

# Transactions

## AMERICAN FOUNDRYMEN'S ASSOCIATION



### Contents

|   |     |
|---|-----|
| Casting Defects Common to Automotive Gray Iron—<br>Their Identification, Probable Cause and Control, <i>by</i><br><i>W. B. McFerrin</i> .....       | 1   |
| The Effect of Welding on the Structures of Some Cast<br>and Wrought Steels, <i>by A. J. Smith and J. W. Bolton</i> ..                               | 31  |
| Composite Molding in a Malleable Foundry, <i>by S. W.</i><br><i>Healy</i> .....   | 72  |
| Cooling and Storage of Foundry Sand, <i>by H. L.</i><br><i>McKinnon</i> .....   | 87  |
| Notes on the Clay Bonding of Molding Sands, <i>by H. L.</i><br><i>Daasch</i> .....  | 113 |
| Melting of Copper-Base Alloys to Retain Physical Prop-<br>erties, <i>by W. B. George</i> .....  | 141 |
| The Effect of Varying the Silicon Content of Cast Iron,<br><i>by F. G. Sefting</i> .....  | 161 |
| Flowability of Molding Sands, <i>by P. E. Kyle</i> .....  | 175 |
| A Comparison of Refractories for Cupola Service, <i>by</i><br><i>J. A. Bowers and J. T. MacKenzie</i> .....   | 193 |
| Report of the Committee on Radiography — 1940.....  | 206 |
| The Relationship Between the Physical and Mineralogical<br>Characteristics of Bonding Clays, <i>by R. E. Grim and</i><br><i>R. A. Rowland</i> ..... | 211 |

# TRANSACTIONS

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## Casting Defects Common to Automotive Gray Iron —Their Identification, Probable Cause and Control

BY W. B. McFERRIN\*, DETROIT, MICH.

### Abstract

*In discussing his subject, the author divides causes of rejection of automotive gray iron castings into 15 general classes including those due to (1) shrinkage and contraction, (2) cracks, (3) hard spots, (4) cold shuts, (5) slag inclusions, (6) gas holes, pin holes and blows, (7) cuts or washes, (8) scabs and rat-tails, (9) drops, rats and crushes, (10) swells, (11) sand inclusions, (12) shifts, (13) not true to pattern, (14) runouts, and (15) rough castings. He discusses each general cause of rejection and several classes of defects under each general heading. He defines each defect, gives the probable cause and explains the methods that may be utilized to overcome them. While this discussion is devoted exclusively to automotive castings, much of the discussion can be applied to casting defects in general.*

### INTRODUCTION

1. Those who have been associated with the production of automotive gray iron castings for the past 12 or 15 years, have witnessed great strides in the reduction of variables in metal, molding, core-making, materials and practice used. In an effort to meet competition and demand for greater durability and quality, the automotive manufacturer has called upon the foundry to produce castings of more intricate design with closer tolerances in all their physical and chemical characteristics.

2. The general trend in the automotive foundries in the past few years, beside the installation of labor saving and high speed

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NOTE: This paper was presented at a Gray Iron Shop Course Session of the 44th A.F.A. Convention, May 9, 1940, Chicago, Ill.

production equipment, has been to cut the sizes of risers, runners, sprues and pouring basins to the absolute minimum required to give sound castings. Castings are made under very closely controlled conditions, thereby increasing their casting yield as much as 50 per cent in some cases.

3. Ten years ago 35 to 50 per cent casting yield was quite common. Now some of the foundries are obtaining yields as high as 65 to 75 per cent and constantly striving to improve. This was made possible (1) by closely controlling pouring temperatures and metal composition, (2) by making a systematic study of gating and risering; thereby making use of all available flask space, as, for example, the grouping or "dead-heading" of smaller castings around larger ones, where the two are poured from metal of the same composition, and (3) by closely controlling the conditioning of the sand, ramming of molds, cores and venting of same.

4. Some of the factors necessary for the production of good automotive gray iron castings may be stated as follows:

1. Adequate equipment properly manned.
2. Adequate supervision.  
Progressive supervision that understands foundry problems and knows how to handle men and equipment.
3. Metal.
  - (a.) Good quality of material for use in the mixing, melting and superheating processes.
  - (b.) Complete knowledge of the chemical and physical properties of the materials used.
  - (c.) Correct operation and control of the melting process.
  - (d.) Metal melted hot (2800 to 2950°F. at spout), poured at proper temperature and rate.
4. As near correct design of casting, pattern and construction of pattern equipment as possible.
5. Proper mold construction of suitable materials, including consideration of cores, such as proper anchoring and venting.
6. Proper core construction of suitable materials, including consideration of proper venting, anchoring and baking to prevent shifts and blows.

7. Suitable cooling time.
8. Proper cleaning operations.
9. Thorough inspection.
10. A complete, clear and concise set of records of each day's operation, correctly compiled and properly interpreted.

5. This paper is presented with the hope that it will promote the classification of various defects common to gray iron castings, their correct identification and cause, thereby helping to clarify this important and complex problem.

#### CASTING DEFECTS COMMON TO AUTOMOTIVE GRAY IRON

6. Casting defects common to automotive gray iron castings are:

1. *Shrinkage and contraction defects.*
2. *Cracked castings.*
3. *Hard spots.*
4. *Cold shuts.*
5. *Slag inclusions.*
6. *Gas holes (pin holes) and blows.*
7. *Cuts or washes.*
8. *Scabs and rat-tails (buckles).*
9. *Drop, stuck to pattern (rats) and crushes.*
10. *Swells.*
11. *Sand inclusions.*
12. *Shifts (cope, drag and core).*
13. *Not True to Pattern.*
  - a. Variation in wall thickness.
  - b. Variation in overall length and width.
  - c. Methods used.
14. *Runouts.*
15. *Rough castings.*
  - a. Conditions of molding sand and mold.
  - b. Conditions of cores.

#### 1 — SHRINKAGE AND CONTRACTION DEFECTS

##### *Classification of Shrinkage Defects*

7. Shrinkage defects may be classified under two general classifications:

1. The first class includes the common voids, draws or sponginess which are present as irregular shaped cavities, the interiors of which are lined with pine-tree-like crystals, metallographically known as dendrites. These crystals, unless discolored by gases, have the appearance of a new fracture. Defects of this kind are generally found near the center of a heavy section or near a change in section thickness and generally are completely hidden until after the casting is partially machined.

2. The second class includes (1) the common "sinks" or "depressions," which make their appearance on the cope side of a heavy flat casting, (2) open or closed pipes that appear on the cope side of heavy bosses, lugs, large bars, or columns cast with the longest side in the vertical plane. The common variation of the above is a "hot tear" or "shrinkage crack," generally appearing on the cope side of castings where a flange or rib joins a heavier section.

#### *Probable Causes*

8. It is beyond the scope of this paper to take up the various methods of gating and risering that are used and the procedure followed in establishing the correct gating method for any production pattern or patterns. Therefore, this paper will deal only with those shrinkage defects that occur occasionally during the year in production castings, due to one or more of the first two factors, given below, being out of balance.

9. These defects are due to such factors as:

- (1) composition,
- (2) pouring temperature and time,
- (3) design of casting, and
- (4) gating and risering.

10. Strictly speaking, these defects are caused by two distinct volume changes that are common to all metals, when cooling from pouring temperature to and through the solidification range. These volume changes are (1) liquid shrinkage, in which shrinkage takes place in the volume of a metal while cooling from pouring temperature until it starts to solidify; and (2) solidification shrink-

age, in which a change in volume takes place while the metal is cooling through the solidification range.

11. According to Saeger<sup>2\*</sup>, Ash<sup>2</sup>, Timmins<sup>3</sup>, Bolton<sup>4</sup>, and MacKenzie<sup>5</sup>, liquid shrinkage for all gray irons per degree temperature drop is approximately the same regardless of composition. This volume shrinkage is approximately 1.1 per cent per 100°C. (or 212°F.) drop in temperature. Shrinkage defects from this source are generally found in castings that are poorly designed, such as those having isolated heavy sections in positions where it is impractical to place gates, risers or other devices for replenishing the supply of molten metal or controlling the direction of solidification.

12. Volume change which takes place while metal is cooling through the solidification range is dependent upon composition, or, as expressed by Dr. MacKenzie<sup>6</sup>, upon "carbon equivalent." The carbon equivalent is equal to total carbon + 0.3 (silicon + phosphorus).

13. This change varies from an expansion of 1.65 per cent in hypereutectic cast iron to a contraction of 5.85 per cent in low-carbon, low-silicon irons<sup>2</sup>. The distribution of the effects of this volume change upon the casting is dependent upon the temperature gradient within the casting, which, in turn, is dependent upon pouring temperature and time, gating, risering and design.

14. This is one of the reasons why foundrymen prefer gating through thin sections into the heavy sections, thereby evening up the temperature gradient as much as possible and increasing the chances of feeding. However, if the temperature gradient is too large to overcome by this method, then risers, shrink bobs or chills will have to be used to produce sound castings free from shrinkage defects.

15. Chills should be used only as a last resort on production castings because, if they are not correctly used, handled, and properly cleaned before using, they will cause more trouble than they correct. Then too, there is the added expense of replacement and the time lost due to the extra operations involved.

#### *True Causes and Corrections*

16. Shrinkage defects, as described under general classification No. 1, are caused from high carbon and silicon, or too high

\* Superior numbers refer to Bibliography at end of paper.

carbon in combination with high phosphorus, or high silicon for methods of gating, risering and sectional thickness (or design of casting). If it is necessary to use high phosphorus and silicon on account of fluidity and machineability, then carbon will have to be lowered to avoid sponginess; remembering that with lower total carbon, greater care must be taken in gating and risering to avoid sinking, piping or hot tears. It has been the writers experience that if phosphorus is kept below 0.25 per cent, carbon and silicon can be varied over a much wider range without encountering shrinkage defects.

17. Shrinkage defects as described under general classification No. 2, are caused from too low carbon which may or may not be coupled up with high silicon and high phosphorus, for method of gating and risering used. If it is found, due to specifications, that a casting must be poured from low carbon metal, even though silicon might be high, risers, shrink bobs or possibly chills, as a last resort, may have to be used to prevent sinking or piping.

18. The casting in Fig. 1 has isolated bosses  $1\frac{1}{4}$ -in. thick and  $3\frac{1}{2}$ -in. high, surrounded by metal  $\frac{3}{16}$ -in. thick. This casting is made two to the mold with bosses *A* and *B* up. Since it is cast from metal having a carbon equivalent range from 4.20 to 4.45, no risers are necessary for the gating arrangement used. However, if the composition was changed to give a carbon equivalent of 4.10, it was found that lug *C* and bosses *A* and *B* showed a depression in center of top, which got progressively deeper as carbon equivalent was lowered. On the other hand, if the composition was changed

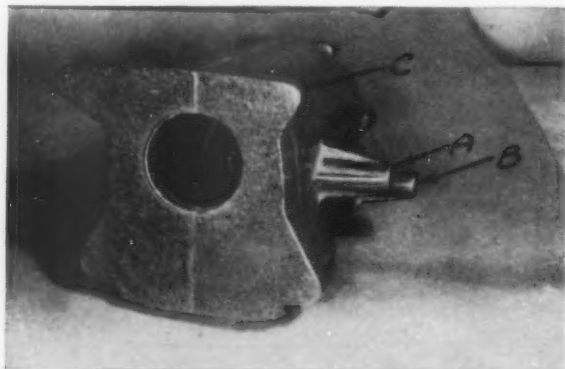


FIG. 1—CASTING WHICH SHOWED DEFECTS IN BOSSES AND LUGS AT POINTS *A*, *B* AND *C*, IF CARBON EQUIVALENT WAS NOT PROPERLY CONTROLLED.

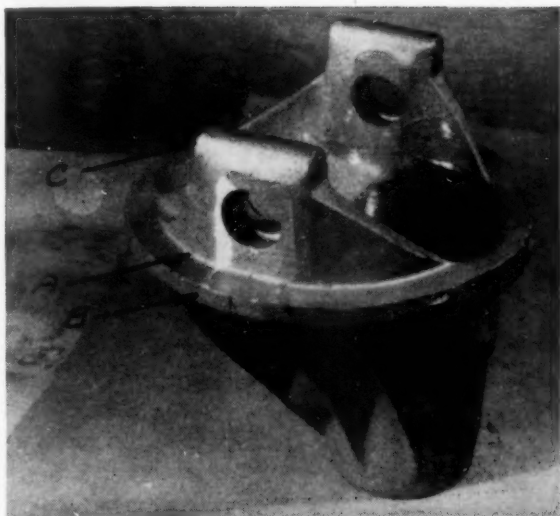


FIG. 2—CASTING WHICH SHOWED DEFECTS IN THE FLANGE AND LUG, POINTS A, B, AND C, IF CARBON CONTENT WAS NOT PROPERLY CONTROLLED.

to give carbon equivalent of 4.60, castings showed signs of internal porosity at junction of lug *C* and curved wall of casting.

19. Castings of the type shown in Fig. 2, are cast two to the mold, large end up, from metal having a carbon equivalent range from 3.80 to 4.20. As long as composition is maintained within that range, provided silicon does not run over 2.40 per cent, and phosphorus over 0.030 per cent and, carbon below 3.10 per cent, the casting is perfectly sound. But, if carbon was below 3.10 per cent, a shrinkage defect appeared as a hot tear at point *A*, at the junction of flange *B*, and piping occurred in lug at *C* in extreme cases.

20. The casting in Fig. 3 is approximately 2-in. thick and weighs approximately 60 lb. and is gated to pour in from 18 to 20 sec. This casting is made on same production line with other castings that require hot iron (2600°F. plus) to run. The majority of castings on this line are poured at temperatures from 2650 to 2750°F. (Temperatures are measured with optical pyrometers which are checked against standard several times per week.)

21. It was found that 15 sec. was minimum pouring time for the composition range required to give a casting of necessary

physical properties. If pouring time was reduced below 15 sec., castings showed shrinkage defects in the form of "sinks" or "depressions" on cope side, in vicinity of gates, unless risers were used to feed castings. Risers are used only as a last resort. In fact, no riser or shrink bob is used on a single production casting in the shop. The pouring weights of our castings range from a few ounces up to approximately 500 lb. This condition was made possible, first, by close cooperation between engineering and foundry staffs and secondly, by closely controlling composition, pouring temperature and time, and making a systematic study of gating.

22. The casting shown in Fig. 4, is cast with crankcase up; one to the mold, and has a pouring weight of approximately 475 lb., from metal having a carbon equivalent range from 3.80 to 4.20. The carbon equivalent is maintained as near 4.00 as possible to give a Brinell hardness in bore of 196.

23. It was found that if carbon equivalent was maintained in this range, provided carbon did not run less than 3.10 per cent, no difficulty was experienced from shrinkage defects. But, if composition was changed to give a carbon equivalent of 3.60, shrinkage defects developed at point A, in the form of a closed pipe, and, if metal of this composition was poured very hot, 2750°F. or over, a combination blow, from excessive trapped gas generated from jacket core assembly, and shrinkage defect, which



FIG. 3—CASTING SUBJECT TO SINKS AND DEPRESSIONS IF POURING SPEED WAS NOT CLOSELY CONTROLLED.

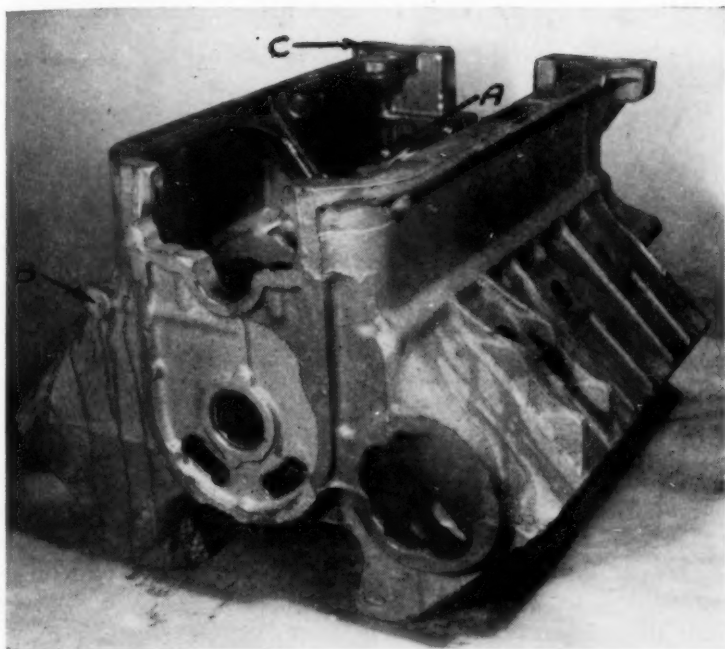


FIG. 4—CASTING WHICH SHOWED DEFECTS AT POINTS *A*, *B* AND *C* IF CARBON EQUIVALENT AND POURING TEMPERATURE WERE NOT CLOSELY CONTROLLED.

caused casting to leak when oil line *AB* and *AC* was drilled, developed.

NOTE. The idea seems to be prevalent among some foundrymen that hard cores, wet cores, green cores, hard rammed molds, sand high in moisture, low in permeability, etc., can cause shrinkage defects. This writer fails to see how these conditions can possibly effect the volume change of the metal, either in liquid state or during solidification. Therefore, the effects of these conditions will be discussed under blows and contraction defects.

#### *Identification of Contraction Defects*

24. Contraction defects are those defects that develop in castings due to internal stresses that are set-up within the casting while cooling from solidification point to room temperature.

#### *Probable Causes*

25. These defects are primarily due to the arrest or prevention of contraction of one section of the casting by another

section, or by hard cores, or hard rammed molds. The tendencies of any casting to warp or crack, due to internal stresses, are governed by the following factors:

1. Variation in rate of cooling.
2. Composition.
3. Strength and temperature of section at stress application.

26. The variation in rate of cooling is by far the most important factor as it determines, to a large extent, the amount of internal stress developed and the temperature at which the stress is applied to any given section. Everything else being equal, the tendency to warp or crack is dependent upon variation in section, or in other words, variation in cooling rate. This fact was well demonstrated by L. A. Danse<sup>8</sup>. For any variation in cooling rate, the tendency to crack or warp is influenced by the solid contraction, which in turn is dependent upon the condition of the carbon, *i. e.*, combined or graphitic. This, in turn, is governed by composition and rate of cooling. Slow cooling tends to increase graphitization.

27. The warping or cracking of any casting is also dependent upon the strength of section when stress is applied. If the section is too weak, the casting will crack, but if it is strong enough to compress or bend a heavier section which is at a higher temperature, then the casting would probably warp. With still stronger sections, the casting may remain in a state of stress, which fact may be easily demonstrated by sawing or machining.

#### *Methods of Correction*

28. The obvious correction for this problem is the elimination of variation in rate of cooling. Some of the methods by which this can be accomplished are: (1) different gating methods, (2) pre-heating certain parts of the mold, (3) change in shakeout time, (4) use of cooling oven, (5) change in position of casting in mold so as to facilitate gating through thin sections, (6) change in design of casting to give more uniform section size, (7) the use of cores that collapse readily and permit free contraction of the casting.

29. In some cases, warping is compensated for by faking the pattern; in other cases, corrected by firmly bedding-in and uni-

formly hard ramming. Under certain conditions cracking or warping of castings has been eliminated by changing composition of the metal so as to give lower combined carbon, thereby reducing solid contraction.

## 2 — CRACKED CASTINGS

### *Classification*

30. Cracked castings may be classified under two general classifications as to cause:

1. Cracks which are due to internal stress developed within the casting. Cracks from this cause have already been discussed under CONTRACTION DEFECTS.

2. Cracks which are due to the action of external stresses upon the casting.

### *Probable Causes*

31. *Rough Handling.* The correction of this defect will be apparent, when, from close observation, it is found when, where and how castings are being cracked in handling process.

## 3 — HARD SPOTS

### *Definition*

32. Hard spots in castings are small areas that can be found without the aid of a microscope and which are large enough to prevent or interfere with machining of the casting. These areas may be high in combined carbon, or may be due to undissolved alloying agent that was added to iron which was too cold to completely dissolve and form a homogeneous liquid. These hard spots will be classified according to the source of their probable cause.

### *Probable Causes*

33. The probable causes of hard spots are as follows:

1. Metal conditions.

- a. Composition, *i. e.*, low carbon, low silicon or too high in carbide stabilizing elements for section thickness.
- b. Cold iron. Cold iron is a cause of hard spots especially if the metal must have alloy additions made to it. Hard spots also occur when thin sec-

tions, that have to be machined, are at points far removed from gates.

2. Molding conditions, cores and methods.
  - a. Flask bars too close to mold cavity.
  - b. Foreign matter in sand, such as lumps of metal, coal or coke.
  - c. Improper use of chills.
  - d. Fins projecting into core, mold face or between core and mold face from thin sections that have to be machined.
  - e. Core rods or wires exposed.

3. Patterns. Patterns improperly designed so as to place thin sections that have to be machined in the cope rather than in the drag where the least chilling tendency is present. If possible, patterns should be designed so as to gate through the thin section.

#### 4 — COLD SHUTS

##### *Definition*

34. The term "cold shut" means a condition where the metal is imperfectly coalesced in one or more places. This may also have the appearance of a "crack," but on close examination, the inner surfaces are found to be perfectly smooth showing no sign of fracture. Sometimes cold shuts are noted in sharp corners or projections which fail to fill out perfectly and are rounded. In some cases, partial coalescence leaves a line of weakness, which later would probably crack if casting got by inspection, and was placed in service.

##### *Probable Causes*

35. The probable causes of cold shuts may be listed as follows:
- a. Cold iron (pouring temperature too low).
  - b. Iron low in fluidity.
  - c. Improper gating.
  - d. Pouring interrupted or slackened before completion.
  - e. Conditions which give rise to excessive gas.
  - f. Hard ramming.
  - g. Cope and drag shift or core shift.
  - h. Worn pattern or core boxes.

*Determination of True Cause and Correction*

36. If the defects result from causes *a*, *b*, *c*, or *d*, or any combination of them, the surface of the casting will have a smooth, shiny appearance, not showing the imprint of the sand pattern of the mold face. To determine which of the above causes produce the defect, check other castings of similar section thickness made on the same production line and poured at approximately the same time. If they show similar signs to those described above, then "*a*" is the cause. Change melting practice or hot metal transferring practice to be sure of hot metal at pouring station.

37. If "*b*" is the cause, the iron may appear normal when first tapped (unless it is oxidized), but it has no "life" or "dies quickly," that is, a white oxide film or scum forms on surface of metal in ladle. This may be caused by low silicon, carbon or phosphorus. Check record of melting practice and chemical analysis, then make necessary changes to give correct composition.

38. If "*a*" and "*b*" are not the causes, then check "*d*." If "*d*" is not the cause, change "*c*" so as to get the metal in the mold and at right places faster.

39. If the defect is caused by "*e*" or "*f*," it should really be classified as a blow. The casting, except in the immediate vicinity of the defect, will plainly show the imprint of the sand pattern of the mold face. The defect occurs as a rounded or oblong hole in the casting wall rather than as that described for "*a*." For corrections see BLOWS.

40. If the defects are caused by "*g*" or "*h*," the wall of the casting will not be of correct metal thickness. For corrections, if "*g*" is the cause, see SHIFT under "*Not True to Pattern*."

41. If "*h*" is the cause, build core box or pattern up to correct size.

NOTE. Core boxes and patterns used on production jobs, where ramming of mold or core is accomplished by the use of sand slinger or core blower, should be checked often for wear, especially boxes or patterns made of aluminum or any material of low abrasive resistance.

## 5 — SLAG INCLUSIONS

*Identification*

42. Slag inclusions in castings are those that appear on the surface of the casting in the vicinity of the gates or along the line

of flow of the metal. The material in these inclusions has a vitrified appearance. The cavities left after removing this material, have a rounded, dull black appearance, not showing the imprint of sand.

#### *Probable Causes*

43. Casting defects resulting from slag inclusions may be classified under two general classifications as to source of slag: (1) inclusions caused by poorly skimmed metal or metal containing entrapped slag and (2) inclusions resulting from the mold.

44. The source of the entrapped slag may be from any one of the following causes, such as: (1) oxidized iron, (2) wet sand bottom in cupola, (3) spout or ladle lining material of low refractoriness, (4) iron melted too cold to free itself of entrapped slag, and (5) dross from ladle additions, alloys, etc., not properly skimmed.

45. Slag inclusions that have their source in the mold, in most cases, will contain a dark cinder-like slag. These inclusions may be due to any one of the following causes: (1) using materials in construction of mold that have too low refractoriness for pouring temperature of metal, (2) incorrect gating practice, and (3) molding sand incorrectly conditioned.

#### *Methods of Correction*

46. A general rule for avoiding slag inclusions in castings is: Operate the cupola correctly using good grade of refractories. Skim metal thoroughly before pouring into molds that are correctly gated, rammed and made from properly conditioned sand that is high enough in refractoriness to withstand the pouring temperature of the metal.

### 6—GAS HOLES AND BLOWS

#### *Gas Holes (Pin Holes)*

47. Defects of this type may be classified under two general classifications as to source:

1. Metal containing entrapped gas or oxidized metal.
2. Condition of the mold.

48. Those holes due to the condition of the metal before pouring are generally distributed throughout the casting but, in most cases, are more numerous in the vicinity of the gates and in thin

flat sections. These holes are rounded, smooth and shiny and do not make their appearance until the casting is partially machined, or is fractured.

49. Those holes due to the condition of the sand are easily distinguished from those due to the metal condition. Such holes are of irregular shape and, in most cases, have a small opening through the surface of the casting. The surface of these holes is dull black or bluish gray in color and does not have a shiny appearance. They are not confined to either cope or drag surface, but generally are more numerous on cope surfaces of flat sections and near the gates.

#### *Probable Causes*

50. Gas or pin holes, due to the condition of the metal, may result from any one of the following causes:

1. Including badly oxidized scrap in cupola charge.
2. Wet sand bottom in cupola.
3. Green ladle or pouring spout.
4. Low coke bed anytime during heat.
5. Coke too large for size of cupola.
6. Too much shot metal in charge.
7. Scrap too large for size of cupola.

51. To determine which of the above are the cause of the defect will require close observation of the entire melting practice and hot metal transfer practice by an experienced foundry metallurgist. Those pin holes that are due to the condition of the sand are simply a multitude of small blows. These small blows are probably caused by one or more of the following:

1. High moisture.
2. Hard ramming.
3. Lack of vent holes in sides of flasks and bottom plates.
4. Sand not thoroughly mixed.

52. In the author's opinion, the chief causes are a combination of high moisture and a sand high enough in permeability so as not to produce large blows, but low enough in permeability to cause very small bubbles of gas to be forced into surface of the casting while it is solidifying.

*Blows*

53. Defective castings of this type are those which show unnaturally smooth depressions on either inner or outer surface of castings. These defects also appear as rounded or oblong holes through wall of casting. The castings, except in the immediate vicinity of the defects, will show plainly the imprint of the sand pattern of the mold or core face. Then there are those defects that show up as large gas holes on cope side of castings or in some heavy section above an improperly vented pocket or cored cavity.

*Probable Causes*

54. Blows may be divided into two general classifications as to cause, namely, mold and core, as follows:

1. Mold Blows.
  - a. Sand conditions.
    1. Low Permeability.
    2. High Moisture.
    3. Too much Seacoal.
  - b. Hard Ramming (produced low permeability).
  - c. Rusty or wet chaplets.
  - d. Character of mold spray.
  - e. Sprue head too low.
  - f. Failure to vent pockets.
2. Core Blows.
  - a. Hard cores.
  - b. Insufficiently baked cores.
  - c. Cores incorrectly vented.
  - d. Seacoal in mixture.
  - e. Oxidized or wet chills.
  - f. Patched cores.
  - g. Permeability of core too high or too low.

*Methods of Correction*

55. *Defects Due to Mold Conditions.* The true cause and correction of the blow or blows will be very easy to determine upon close examination of the defect as to appearance, location and correlation with records of that days production; provided complete records are kept. For example, if the blow is due to the

condition of the molding sand, such as low permeability, in most cases, it will show up as an unnaturally smooth depression on heavier sections or as a hole in thin sections, with the largest end of the hole next to the green sand. But, if the blow was due to high moisture and low permeability (hard ramming), it will appear the same as that described above, with the exception that it will have little needles or rough projections of metal protruding from contour of defect.

56. To determine if low permeability was due to hard ramming or fines (fine grains of sand, dehydrated clay, etc.,) check records of sand test results. If permeability was correct, then low mold permeability was due to hard ramming. *Remedy*—Reduce ramming. However, if sand test results showed low permeability with correct moisture and strength, then low mold permeability was due to sand containing excess fines. *Remedy*—Reduce fines, or add clay-free silica sand.

57. If blow was due to too much seacoal it will appear the same as that for low permeability with the important exception, that before cleaning the casting in the vicinity of the defect, it will have a coating of black shiny flake carbon. *Remedy*—Reduce seacoal additions to facing sand.

58. If defects were due to "c" or "f," the location of the defect would indicate the cause. The correction is obvious.

59. If blow was due to "e," the defect will show on cope side of casting, generally on some section of the casting that protrudes above the main body of the casting and approaches the height of the sprue. *Correction*—Use deeper cope flask; use runner box on top of cope; reduce ramming over this section, or vent freely.

NOTE. Cope and drag flasks and bottom plates should have ample vent holes.

60. *Defects Due to Core Conditions.* If blows are due to conditions such as "a," "b," or "d," under core blows, the blow will show up as a depression on the inner surface of the casting, as a hole through wall of casting, or as trapped gas in a heavier section, with a worm hole or spongy section leading from cavity, due to trapped gas, to the surface of the core. It will also be noted that metal did not lay firmly against the cored surface, but did against the mold surface, except for the area directly over

defect. Check records of core sand mixtures, baking temperature and time to determine which of the above three variables were at fault. *Corrections*—If “a,” use less binder; if “b” increase baking time or temperature; or if “d” reduce seacoal content.

61. If core blow is due to either “c,” “e,” or “f,” the defect will make its appearance in the form of a depression, blow hole, or trapped gas pocket above or in the line of flow of the metal from that part of the core causing the defect. The location of the defect and the appearance of the cored surface in the vicinity of defect will indicate which of the above three are at fault.

NOTE. An improperly placed vent, or a vent that is not properly taken off through mold, does more harm than no vent at all.

62. To determine if the defect was due to “g,” it will only be necessary to check records of core sand mixtures, baking time and temperature, and correlate this information with the appearance and location of the defect. The correction is use of finer sand.

NOTE. The explanation of a blow due to high permeability is that the heat from the metal will penetrate a highly permeable core at a much faster rate than it will one of low permeability. In other words, the rate of gas evolution from any particular core (the binder content, baking temperature and time being the same) which is exposed to the same heating conditions, will vary according to permeability.

#### 7—CUTS AND WASHES

63. Defective castings, that are due to cuts and washes, will have rough lumps of metal, or rounded corners which should be sharply defined, or at some point of the casting's surface. At other points, along the line of flow of metal, will be rough granular depressions or holes.

##### *Probable Causes*

64. Probable causes for this defect are:

- a. Soft ramming.
- b. Low moisture.
- c. Low green strength (low dry strength).
- d. Improper gating.
- e. Type of clay bond used.

*Determination of True Cause and Correction*

65. If the cut or wash is due to "a," the casting will probably show signs of a swell (casting not true to pattern, showing deformation due to displacement of sand by the metal) in vicinity of the defect. *Correction*—Increase ramming.

66. If "b" or "c" is the cause, check sand test records and if either moisture or strength is low, make the necessary corrections. That is, increase moisture or clay additions to sand.

67. If "e" is causing the defect, the latter will probably be in the vicinity of the gate or part of the sand around the gate may be cut or washed away. This may be due to (1) gate being designed so as to produce nozzling effect, (2) arrangement of gates, as for instance, gating into casting so that large volume will have to flow over sharp corners or projections of mold face, and (3) metal being poured from too great a height directly into sprue.

NOTE. A pouring basin or cup should be large enough to permit metal pourer to quickly choke down sprue without pouring directly into sprue, or splashing metal all over top of mold. The down sprue should have a cross-sectional area slightly larger than the combined cross-sectional area of the gates, but less than the cross-sectional area of the runner. The width of the runner should be less than its height. The gate should be flat and slightly wider at junction of gate and casting than at junction with runner.

If all other factors mentioned above are correct, then the defect is probably due to "e", especially if the source of supply of the bonding clay has changed and the new clay gives much lower dry strength than that used formerly.

In general, among the automotive foundries, there are three general sources of supply for clays, namely, (1) Wyoming, which clay gives high green strength and high dry strength, (2) Ohio, Indiana, and Illinois, which clays give a medium green strength and low dry strength in comparison to the Wyoming clays, and (3) Alabama and Mississippi which clays have been used by some of the automotive foundries recently. These latter clays have somewhat higher green strength and lower dry strength than any of the previous mentioned clays. For more information on the subject of cuts and washes, see paper presented by H. W. Dietert and E. E. Woodliff<sup>9</sup> before the 1939 Convention of the American Foundrymen's Association.

### 8—RAT-TAILS (BUCKLES) AND SCABS

68. In the author's opinion, "Rat-tails" and "Buckles" are one and the same defect in that they are caused from the sand hav-

ing too high expansion. "Rat-tails," (small buckles) are produced when the condition of the sand, pouring temperature of the metal and section thickness of the casting are such as to cause enough expansion in mold face to make a small ridge of sand on the mold face which produces a defect on the surface of the casting, having the appearance of a place where a rat has dragged its tail. But if conditions had been such as to produce enough expansion of the sand to cause the mold face to buckle then the resultant defective casting would be classified as a "buckle."

69. The author has seen "rat-tails," "buckles" and "scabs," all on the same casting. The casting was a flat plate of about 18-in. diameter and 2-in. thick, gated to pour in 16 to 18 sec. The "buckles" and "scabs" were on the cope surface of the casting and in the vicinity of the gates. The "rat-tails" were also on the cope face of the casting, but on that part of the surface farthest from the gates.

#### *Identification*

70. "Rat-tails" (small buckles) are those defects on the flat surfaces of castings that have the appearance of a ridge, the top of which is slightly above the normal surface of the casting. One side of the ridge gradually slopes back to normal surface of casting, with the other side dropping off suddenly to slightly below and then sloping gradually up to the normal surface of the casting.

71. Scabs are those rough spots, usually on a thick-walled portion of the casting, the wall being slightly thicker than normal, porous and containing a layer of sand underneath the surface of the rough spot. Scabs are generally more numerous on the surface of the casting in the vicinity of the gates, or on the surface of heavy-walled castings where the sand is heated hot enough to contract.

#### *Probable Causes*

72. According to Dietert and Valtier,<sup>7</sup> "rat-tails" occur in light weight castings where temperature of sand does not reach contraction point, but sufficient heat is present to expand the sand.

73. Another quotation from the same paper, as to the cause of the scab, states: "The combination of excessive expansion and contraction, as obtained when sufficient weight of molten metal is

present to raise the temperature of the sand to contraction point, is undoubtedly the best explanation of the direct cause of a scab."

74. Some of the causes of rat-tails and scabs are as follows:

1. Hard ramming.
2. Low permeability (sand contains too much fines).
3. High moisture.
4. High strength.
5. Low seacoal content.
6. Change in type of clay used.

#### *Methods of Correction*

75. According to the previous reference, "Expansion of molding sand may be reduced by (a), increasing grain size (b), reducing fines (c), addition of combustible materials (d), reducing the mold hardness (e), increasing permeability and (f), reducing moisture."

76. Opposing stresses between expansion and contraction may be reduced by (a), increasing grain size (b), reducing the fines (c), reducing mold hardness (d), increasing permeability (e), reducing moisture and (f), reducing clay content.

#### 9—DROPS, RATS, CRUSHES

77. Defects of this type are easy to distinguish from other defects. A defective casting due to a "drop" will have a large rough lump of metal protruding above normal surface of the casting, under which, in some cases, will be a sand pocket. In other cases, it will occur along the line of flow of the metal.

78. Defects classified as "rats" by some foundrymen, are those due to part of the mold face sticking in a pocket on the pattern, or dropping off before drag was placed on conveyor, or before cope was placed over or on drag.

79. Defects classified as crushes are those castings showing deformation along parting line or around core prints.

#### *Probable Causes*

80. Some of the causes for defects classified as drops and rats are:

1. Low green strength.
2. Low or high mold hardness.

3. Not enough draft on pattern.
  4. Molding machine draws too fast.
  5. Pattern loose.
  6. Bearing surfaces of flask or pattern worn or not properly cleaned, which causes flask to rebound when rammed on jolt machine.
  7. Worn bumping pad on molding machine.
81. Some of the causes for defects classified as crushes are:
1. Low green strength.
  2. Core print too large for print on pattern.
  3. Sloppy closing.
  4. Mismatched cope and drag patterns.
  5. Worn patterns and core boxes.
  6. Pattern not correctly mounted.
  7. Core print too small for size of core.
  8. Improper clamping of mold.
  9. Use of weights that are too heavy.
  10. Worn stripping plate on molding machine.
  11. Improper bedding of molds on bottom plates or boards.

#### *True Causes and Corrections*

82. To establish the true cause and correction for any of the above mentioned defects will require close observation on the part of an experienced foundryman and correlation of these observations with the conditions of the molding sand, cores, etc.

#### 10—SWELLS

83. Defects classified as swells occur in those castings which show deformation due to displacement of the sand by the metal.

#### *Probable Causes*

84. Some of the conditions causing these defects are:
1. Soft ramming.
  2. Mold not properly bedded on bottom plate.
  3. Flasks not rigid or not containing enough bars (supports for the sand).

*Method of Correction*

85. The true cause will be easy to identify upon close examination of the defective casting and observation of molding practice. The correction will then be obvious.

**11—SAND INCLUSIONS**

86. Sand inclusions in castings are those cavities of irregular shape and size, the inner surface of which plainly shows the imprint of a granular material around which metal would flow.

*Probable Causes*

87. The probable causes of sand inclusions are as follows:

1. Sloppy molding practice (carelessness).
2. Cuts and washes.
3. Crushes.
4. Improper gating.
5. Sand incorrectly conditioned.

88. It has been the author's experience that, in the majority of cases, defective castings due to sand inclusions were the direct result of sloppy molding practice, such as (1) blowing off pattern into unclosed drag; (2) loose sand falling into drag from overhead equipment, molders clothes, outside edges of cope flask, etc.; (3) loose sand in pouring basin or sprue; and (4) blowing loose sand out of sprue and pouring basin (while cope is resting on stripping plate of molding machine after drawing pattern) with high pressure air line in such a way as to cause loose sand to hit pattern and rebound and stick on cope surface of mold.

**12—SHIFTS (COPE, DRAG, AND CORE)**

89. A shift is indicated in castings in which cope and drag portion do not exactly match at parting line or when one wall of a casting containing a cored cavity is thinner and the other wall is heavier than called for by the specification. The former is a mold shift; the latter is a core shift. That portion or section of a casting improperly located, which was formed by a core, is also known as a "core shift."

*Probable Causes*

90. Probable causes of shifts are as follows:

1. Worn pins and bushings.
2. Cope and drag pattern not exactly matched.
3. Improper clamping in conjunction with sloppy pins and bushings.
4. Rolling weighted molds on gravity conveyor.
5. Cores not set correctly.
6. Lack of ample core prints or chaplets.

*Methods of Correction*

91. The true cause will be apparent upon close examination of the defective castings, molding equipment and practice, core equipment and practice. The correction then will be obvious.

## 13—NOT TRUE TO PATTERN

92. When a casting is not true to pattern, this defect may be due to three classes of causes, namely, (1) those causes which produce a variation in wall thickness, (2) those which cause variations in overall length and width, and (3) and those due to methods used. The following are the definitions of these major classes of causes, the reasons for their occurrence and methods of correction.

*Variations in Wall Thickness*

93. A casting which shows more or less metal at one or more points than called for by specifications.

*Probable Causes*

94. The probable causes of this defect are as follows:

1. Worn core boxes or patterns.
2. Too much rapping of pattern or core box before or while drawing.
3. Cores not true to boxes.
  - a. Due to not using driers (supports) for certain parts of the core to prevent sagging while baking.
  - b. Rough handling.
4. Pattern not properly mounted.

5. Springing of pattern.
6. Cores not properly jigged, gauged, and assembled.
7. Cores not set correctly.

*Variations in overall length and width*

*Probable Causes*

95. The probable causes of this defect are as follows:

1. Excessive rapping of pattern.
2. Metal shrinkage and contraction not uniform.

*Methods Used*

*Probable Causes*

96. The probable causes of the defect under this classification are as follows:

1. Excessive tumbling, shot blasting or grinding.
2. Sagging of casting.
  - a. Due to being shaken out too soon.
  - b. Casting not properly supported while being heat-treated.
3. Warping—see CONTRACTION DEFECTS.

*Methods of Correction*

97. The determination of the true cause and correction will require detailed examination of the defective casting or castings, and the correct correlation of this information with those probable causes mentioned above that might produce this defect.

## 14—RUNOUTS

98. Defective castings due to runouts are those castings lacking in completeness due to molten metal leaking out of some part of the mold cavity while pouring or after pouring is completed.

*Probable Causes*

99. The probable causes of this defect are as follows:

1. Soft ramming between mold cavity, sprue or runner, and the edge of flask.
2. Mold not properly bedded.
3. Improper clamping.

4. Bearing surfaces for flask on pattern worn or not properly cleaned.
5. Sand or metal on joint of flask.
6. Warped flask.
7. Flask too small for size of casting.
8. Sprue too near side or runner too near joint of flask.
9. Large core or mold vents too near surface of core or mold cavity, especially if vents are taken off through sides of flask or bottom plates.

#### *Methods of Correction*

100. The correction will be obvious when the true cause of the runout is found from observation. It has been the writer's experience that the majority of the defective castings caused by runouts are due to carelessness.

#### 15—ROUGH CASTINGS

101. The term "rough castings" has a rather wide and varied meaning. What may be classified as a rough casting for one job may be classified as a smooth surface for another, for instance, the surface of a casting that has to be enameled in comparison to that of a flywheel. The term "rough casting," as used here will be construed to mean those castings having surfaces so rough that they are unsuitable for purpose intended, unless extra cleaning or polishing operations are performed on them.

#### *Probable Causes*

102. The probable causes of rough castings may be classified as follows:

##### *Condition of Molding Sand and Mold*

- a. High moisture.
- b. High permeability.
- c. Low flowability—
  1. High strength.
  2. Low moisture.
  3. Sand containing lumps of coal, slag, metal, cores, etc.
- d. Sand too low in seacoal content.

- e. Hot sand.
- f. Low mold hardness.
- g. Mold cavity not correctly sprayed or coated.
- h. Pouring temperature too high for molding materials used.
- i. Improper gating.

#### *Condition of Cores*

- a. Sand too coarse.
- b. Baked too rapidly.
- c. Soft rammed.
- d. Cores incorrectly sprayed, dipped or coated.
- e. Type of coating (core-wash or blacking) used.
- f. Pouring temperature too high for core materials used.

#### *Determination of True Cause and Correction*

103. *Rough Surface Due to Condition of Molding Sand and Mold.* If the rough surfaces are caused from *a, b, d, e, or f*, or any combination of them, the surface of the casting will probably be uniformly rough. To determine which of the above are at fault, check sand test records. If moisture, permeability and strength are correct, and the surface of the casting had a dark bluish-gray tint, then the rough surface of the casting was due to hot sand sticking to pattern. *Remedy.* Reduce temperature of sand by better method of aerating or increasing sand storage.

104. If this method be too expensive for volume or production, then arrange to heat patterns up to slightly above temperature of the sand.

NOTE. Hot sand does not stick to a pattern made of cast iron or brass as much as it does to one made of aluminum.

Another alternative is to spray the pattern lightly with a mixture of one part lard oil to ten parts of kerosene (by volume) after every second or third mold. This will eliminate this condition providing there is not too much difference between the temperature of sand and pattern.

105. If moisture is too high, the surface of the casting may appear the same as that described for hot sand, excepting for small depressions on cope surface of the casting typical of high moisture blows (see *BLOWS*). *Remedy.* Reduce moisture.

106. If the permeability was found to be too high upon examination of sand test records the remedy is to reduce permeability by the addition of a finer sand or else reduce the coarse grains. In most cases, for quick results, it is cheaper to add a finer sand, being careful to add it in such a way as to have it uniformly distributed throughout system.

107. If "d" is at fault, the surface of the casting will be uniformly rough and not have a dark bluish-gray tint, or at least that portion of the surface of the casting corresponding to that part of the pattern that was covered with sand of too low seacoal content. *Remedy.* Increase seacoal additions.

108. If "f" is at fault, the surface of the casting, in addition to being uniformly rough, will probably show signs of a "swell." *Remedy.* Increase mold hardness.

109. If "c" is at fault, the surface of the casting will have rough projection of metal protruding from it. *Remedy.* Increase flowability of the sand which will eliminate the voids in mold face.

110. Cause "g" will only be responsible when the surface finish of casting is dependent upon some coating that is either sprayed, brushed or dusted on the mold face. Examine the surface of the casting and the coated mold face to determine if it is the type of material used or the method in applying it that is at fault. *Remedy.* Determine by experiment the correct material and method of applying it.

111. If "h" is at fault, the casting's surface will have a rough, sandy, burnt appearance. *Remedy.* Use materials in the construction of the mold that have higher sintering points, or reduce pouring temperatures of the metal. The author prefers to pour the metal hot (2600°F. plus) and use materials in construction of molds and cores to withstand it.

112. If "i" is at fault, the surface of the casting will show signs of "cutting" or "washing," or have a rough sandy appearance in the vicinity of the gates. *Remedies.* See "cuts" and "washes" or "h" above. This defect, in some cases, can best be corrected by changing gating practice so as not to overtax the sand in the vicinity of gates.

113. *Condition of Cores.* If "a" is at fault, the cored surface of the casting will be uniformly rough. *Remedy.* Use finer sand or

else coat the surface of the core by dipping or spraying with a core wash. The best wash for any particular job only can be determined by trial and error method or past experience.

114. If "b" is at fault, the cored surface of casting will have fins protruding from it. This condition may be due to either too rapid baking or using sand that had too high a rate of expansion and contraction. To determine which, examine the surface of cores after baking. If the surface of the cores are cracked, then "b" is at fault. *Remedy.* Use lower baking temperature.

115. If "c" is at fault, the surface of the core will contain voids and the cored surface of the casting will have rough projections or lumps of metal on it. *Remedy.* Ram core harder.

116. If "d" or "e" is the cause, the remedies are the same as those discussed for "g" and "h" under conditions of molding sand and mold.

117. If "f" is at fault, the cored surface of the casting either will show signs of "cuts" and "washes" or a burnt-in or sandy appearance. If it shows signs of "cuts" or "washes," then the binder or baking time and temperature are at fault. *Remedy.* Use a binder that will not break down as readily and bake the core at as near the optimum baking time and temperature as possible.

118. If the cored surface of the casting shows a "burnt-in" or "sandy appearance," the remedy is the same as that for "h" under conditions of molding sand and mold, if cores are not coated.

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## The Effect of Welding on the Structures of Some Cast and Wrought Steels\*

PRESENTED BY THE LUNKENHEIMER CO., METALLURGICAL RESEARCH DIVISION, CINCINNATI, OHIO, PER A. J. SMITH AND J. W. BOLTON

### Abstract

*The Lunkenheimer Co. conducted an investigation of the relative weldability of cast and wrought steels, studying the structures of welds under various conditions of preheating, and observing and accumulating data on the reaction of the steels studied with regard to hardenability, grain coarsening, formation of hard constituents, etc. The paper shows that, under the conditions of the investigation, cast steels show at least as good, and in many cases better, weldability than comparable rolled products. The investigation definitely explodes the theory, held by some, that cast steel lacks the weldability of the rolled products.*

### INTRODUCTION

1. The art of welding has been practiced for many centuries. It was entirely due to the knowledge of the process of welding that iron and steel became useful, welding being the principal process employed in the manufacture of steels of plastic origin, since it was impossible to attain the temperatures necessary for melting until comparatively recently. Welding originally implied the local joining of solid metals, usually under the application of heat and pressure (though in certain cases not necessarily so, as for example in the joining of gold and lead). This process is still widely practiced, although more often today in a somewhat modified form.

2. With the ability to attain extremely high local temperatures, a development which has taken place almost wholly within

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our own century, the definition of welding has been extended to include the joining of metals through the local fusion, either of the metals themselves or, more often, of a third metal placed between the parts to be joined. This welding process is becoming more and more widely used and appears to be rapidly superseding other types of joining, such as bolting and riveting, for many applications. Joints of much higher strength can be obtained and such joints are pressure tight, a quality which finds peculiar adaptability in the production of pressure vessels and fittings.

3. The art of fusion welding has achieved a high degree of perfection. Nevertheless, the scientific investigation of the process apparently has been largely ignored by many of its users. It is well known that high stresses may be developed in the welding of certain steels, and, in steels not of the best weldability, preheating and stress-relief annealing have been advocated. Preheating and annealing temperatures recommended have been more or less arbitrary and it is quite evident that in a highly stressed part, the recommendation of these temperatures should be made more precise and must be backed by sound and thorough investigation.

4. For this purpose, a program of research was initiated by The Lunkenheimer Co., to investigate the effects of welding on certain steels widely used in the valve and fittings industry. The technical aspects of the investigation have been reported<sup>1</sup>. It was felt, however, that certain findings might prove instructive to foundrymen and that a useful purpose would be served if the work were treated from that aspect and placed in a more readily available journal for reference purposes. Such is the intention of this paper.

#### THE WELDING OPERATION

5. In fusion welding, the temperature of the weld metal to be deposited is raised above the melting temperature. This molten metal is then flowed into a position in the base metals prepared for it. The temperature of the base metal during the depositing, may vary over a wide range. At the lowest temperature at which joining is possible, the temperature of the base metal is only raised to that point where wetting by the molten metal takes place and the bonding is brought about almost purely through surface attraction. Soft soldering is the familiar example of this.

<sup>1</sup> Bolton, J. W. and Smith, A. J., "Welded Structures in Some Cast and Wrought Steels," *THE WELDING JOURNAL*, vol. 18, no. 11, November 1939, pp. 398-S—417-S.

6. If the temperature of the base metal is raised above this, a certain amount of diffusion between liquid weld metal and solid base metal takes place. A stronger type of joint results. Brazing is an example of this type of joining.

7. Finally, there may be local melting of the base metal and diffusion, or other mixing, of liquid weld metal and liquid base metal taking place. Under suitable conditions, this often gives the strongest possible joint. It is this type of joint that is normally considered in fusion welding.

8. Nevertheless, in studying the effect brought about in fusion welding, we should not for an instant forget the other two types, for they can and often do occur in a supposedly fusion welded joint. This condition is most likely to occur in the welding together of widely dissimilar materials, such as plain carbon or low alloy steels welded to very high alloy steels. To predict the strength of a weld of plain or low alloy steel to certain stainless steels for example, is distinctly hazardous. The equivalent of a sweated joint would be found if weld rod and base metal did not mix, even if the base metal were melted.

#### *Conditions in Welding*

9. The conditions of welding are very important in attaining a strong, sound weld. The metals are carried to a temperature where gas solubilities are very high and where oxidation may be excessive. Oxygen, nitrogen, and probably hydrogen, must be kept out or minimized, and conditions must be maintained such that carbon is neither picked up nor burned out. Controlled atmospheres usually are used to avoid difficulties in these respects.

10. To a degree, a proper atmosphere can be obtained directly with a flame but greater ease of protection is probably better attained with a coated welding rod, the coating breaking down at the elevated temperature to give a local protective atmosphere and also a fluxing effect. But the type of coating must be governed by the work to be done, for the action of the coating materials is not the same for all base metals.

#### *Ideas on Aluminum-Killed Steels*

11. Among many welders, aluminum-killed steels are frequently thought of as unweldable. It has been considered difficult and costly to get a radiographically sound weld with such steel.

Yet, to the steel foundryman, aluminum is practically indispensable. Getting sound castings is his first objective. Securing sound welds in an aluminum killed steel is a problem for the welding metallurgist and it can be done. Attempting to pour castings from semi-killed or rimming steel borders on the ridiculous. A goodly degree of success in welding aluminum-killed steels has been attained through use of proper welding rods and proper coatings. It seems only a question of time until proper coatings, rod analyses, and techniques will be developed to make these welds as readily as those in non-aluminum-killed steels.

#### *Data on Preheating Welds*

12. These few statements approximately cover the welding story as it affects the welding engineer. Only one other point usually intrudes itself and that is the elimination of welding stresses. When necessary, these stresses often may be kept at small value through corrective design. In other cases, alteration of design cannot be permitted and relief annealing usually is resorted to. For this same purpose, and also for the elimination of any brittle structures that might be produced, preheating is sometimes used. This use of prior or subsequent heat-treatment leads to a point which appears to have been largely neglected.

13. Investigation of the literature, to ascertain the proper preheating temperature of a certain common steel, revealed that there was a definite recommendation for preheat but absolutely no factual data could be found which would justify the recommendation. A subsequent study showed that the utility of the steel in question would be practically ruined using the recommended heat treatment. Information regarding the effect of welding on the structure of steel is exceedingly meager. But none who spend a great deal in time and money on the practice and study of heat treatment will fail to realize its importance.

14. In the operation of fusion welding, as earlier defined, base metal is heated locally above its melting point. It is then cooled at a rate largely dependent on the nature and size of the weldment. If but a single bead is laid with no preheating, the cooling rate will be high and might even amount to a drastic quench, particularly if the base metal is of heavy section. With laying of more than one bead, automatic preheating takes place and consequently heat abstraction is slower, approximately a slow cool.

15. The temperature to which the molten pool of weld metal is raised depends on the speed of welding and power input with the arc, or manner of manipulation if a flame is used. In normal welding operations, it probably runs well in excess of  $3000^{\circ}\text{F}$ . In the case of heavy base metal sections, metal as little as  $\frac{1}{8}$ -in. from this molten pool may not be heated above the critical temperature and the rate of heat abstraction is very great. This would imply a temperature gradient at the instant of welding of more than 12,000 degrees per inch. With this exceedingly high gradient rapid quenching will naturally follow. The temperature condition at the instant of welding across a welded section is shown diagrammatically in Fig. 1<sup>2</sup>.

16. The base temperature in this diagram will, of course, be the preheating temperature, if any. It will be seen that all of the metal beyond a certain point is raised above the critical temperature. Alteration of the structure of this metal will take place and

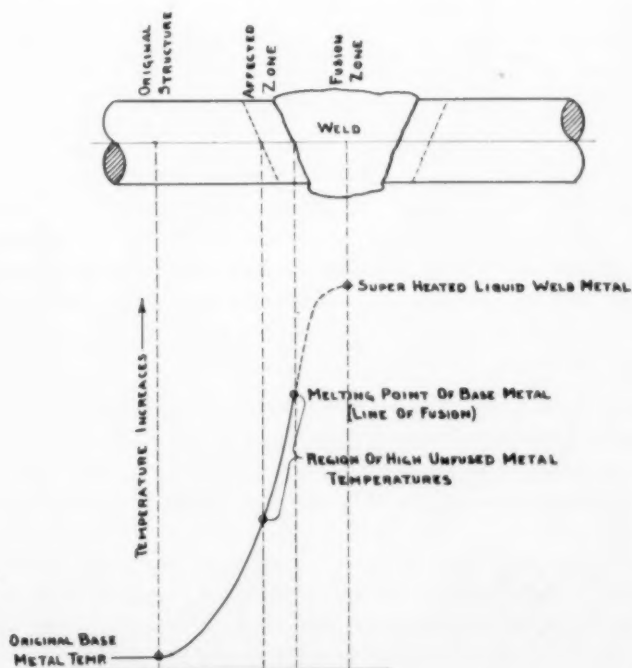


FIG. 1—TEMPERATURE ATTAINED ACROSS WELD SECTION.

<sup>2</sup> After *Welding Handbook*.

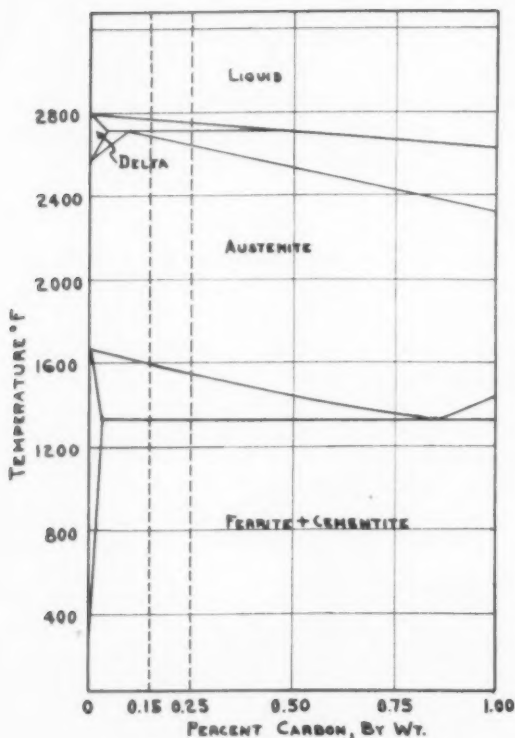


FIG. 2—SECTION OF IRON-CARBON DIAGRAM.

the final structure will depend on how high a temperature is attained and how rapidly the heat is subsequently dissipated. If the rate of heat dissipation is sufficiently slow, approximately equilibrium conditions will obtain.

17. In Fig. 2, a portion of the iron-carbon constitutional diagram is given. Vertical dotted lines are drawn to illustrate the fields traversed in cooling a common structural grade of steel at 0.15 per cent carbon and a common casting grade of 0.25 per cent carbon.

18. Some of the base metal nearest the weld will be carried into the liquid zone in accordance with Fig. 1. Metal more remote from the weld will be carried into intermediate regions and metal yet farther away will not get quite above the lower critical temperature at some 1335°F. On very slow cooling, the weld-affected

metal should come back into the ferrite plus cementite field with the carbon in areas of lamellar pearlite uniformly distributed in areas of free ferrite. Actually, though, even with such a degree of equilibrium, the high temperature history will be evident, for the size to which the grains grew at the high temperature, will still be apparent. This will be true regardless of how rapidly the metal is cooled after welding and will be more pronounced as the cooling velocity is increased.

### *Gradients in Welds*

19. In the normal operation of heating metals, if a gradient of some sort is present, such as composition, strain, or temperature, the crystalline grains will tend to grow, the growth being greater as heating is increased and as the gradient is increased. In ferrous alloys, this grain growth suffers complications when the metal is heated into a new phase field. However, any phase will show its greatest grain growth at the top of its temperature range and least at the bottom. Hence, in heating an iron alloy of a composition, such as indicated by one of the dotted lines in Fig. 2, the grains will increase in size with heating from room temperature up to the first horizontal. However, little grain growth will normally be found with this heating unless one of the required gradients is present in sufficient amount.

20. The commonest gradient will be a strain brought about through cold work. In heat-treated castings, or the hot-rolled shapes which are usually welded to them, this strain will be absent or nearly so, and grain growth in this region below the first horizontal usually is not noticeable.

21. On heating past the horizontal into the austenite field, a new type of crystal structure is formed with an entirely new array of crystalline grains. Carbon, which was almost insoluble in the low temperature field, now becomes completely dissolved. Diffusion of this carbon will take place until eventually the carbon atoms will take completely random positions whereas before they were segregated in the pearlite areas. Also, with the change of crystalline structure, a dimensional change will take place, producing a considerable amount of stress and strain. With increasing temperatures, this stress will be relieved through readjustment of the whole lattice structure. However, this readjustment will not be absolutely uniform. There will be temperature and concentration gradients also, and grain growth will become more marked the

higher the temperature is carried in the austenite field. Grain growth will be excessive as the temperature approaches the second horizontal at some 2700°F. where melting commences to take place.

22. Since the alloy becomes partly molten at this horizontal, the effect of the transformation of some of the solid austenite to delta iron may be neglected. On cooling the sample back to room temperature, traces of the high temperature history will be retained. On cooling from the austenite field into the austenite + ferrite field, ferrite will be rejected at the austenite grain boundaries. The normal cooling rates do not permit sufficient time for random distribution of the ferrite and pearlite areas, but the ferrite first rejected will continue to occupy what were once austenite grain boundaries. Also, as a rule, the size of the ferrite grains will follow the size of the austenite grains from which they were formed. Other materials, such as impurities which may have an increasing solubility with increasing temperatures, also will be rejected at the austenite grain boundaries. If the boundary surface is large, as would result from very small grains, the effect of this rejection is practically negligible. If, however, the boundary surface is small, resulting from large grains, these rejections assume great importance and low strength and low ductility are the usual consequence.

#### *Structure of Welds*

23. As already stated, a section through a weld and the adjacent base metal will show this whole sequence of events. In Fig. 3<sup>2</sup>, a diagram is given of such a structure. The fused weld-metal and base-metal, which also has been fused, will show the typical columnar crystals growing away from the base metal, the direction in which the heat was abstracted. Below this region will be found coarse grained metal which had been heated to near the melting point and, receding from the weld, the grain size will become progressively finer. Finally, metal is encountered which will have just passed the lower critical temperature and which will be very fine grained. Below this point, the original structure is found, except where slight grain-growth might have taken place. (The reader may here refer to Figs. 6, 7 and 8 for a microscopic demonstration of this.)

24. Impressed on all these structures will be the effect of cooling rate. The cooling rate will be very rapid in the event of

<sup>2</sup> *Welding Handbook.*

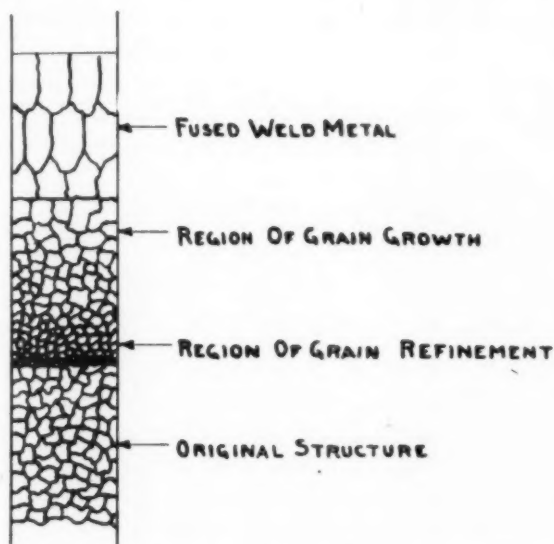


FIG. 3—SCHEMATIC DIAGRAM OF AFFECTED ZONE IN WELDED MATERIAL.

a single bead laid in heavy sections without preheat. If, as is customary, a number of beads are laid, the effect will be to draw or temper the structures resulting from the more rapid cooling rate of the first bead. The same result will be arrived at through preheating.

25. In the work of The Lunkenheimer Co., the severest quenching action has been found right at the weld interface. In some cases, a fully martensitic structure was developed. Such a structure is naturally undesirable and, while the laying of subsequent beads will temper this structure, preheating often must be resorted to in order to prevent cracking. Since it is possible to have martensite developed in a weld, it will be seen that practically all of the structures that would be found in a normal heat-treating operation could occur, and, as will be shown later, structures may be found quite different than those usually found.

#### *Test Procedure*

26. In the original work, bars of  $2\frac{1}{2}$ -in. diameter were butted together and held tightly by means of a screw at the centers. A semi-circular groove was cut in the outside butted edges for arc-welding, and very near the edge of the groove—about  $\frac{1}{8}$ -in. away—holes were drilled and thermocouples were inserted in them. Four

couples were used in each bar, the couples being placed directly across the groove from one another and in the 0,  $\frac{1}{4}$ ,  $\frac{1}{2}$ , and  $\frac{3}{4}$  positions around the bar. A single bead was laid in the groove while the bars were being rotated and, by means of the thermocouples, a complete record of the heating and cooling cycle was taken for each position as welding progressed. The welding was carried out under constant conditions for three-quarters of the way around the bar.

27. In certain cases, a solid bar was used around which a groove was turned and welding was carried out under exactly the same procedure as in the other tests.

28. Sectional samples were then cut out at the initial and final welding positions, each sample containing the weld-affected portions of both bars and the weld metal joining them. For study of the effect of preheating, electric furnaces were placed around the bars and carefully controlled to give constant temperatures. Preheats up to 600°F. were used in these studies.

#### TYPES OF STEEL USED

29. In the investigation, five types of cast steel and three types of rolled steel of standard grades were used. The specifications with which they complied are given in Table 1. All of them are regularly used for valves, pipe and fittings in high temperature steam service and are considered in the trade as of welding grade. A fourth type of rolled steel was also used, a free cutting stainless, which is not considered of welding grade, but which will be used here to demonstrate points less clearly brought out in the other steels.

#### *Electrodes*

30. Three types of electrodes were used:

(1) Electrode 1 was a cellulose coated unalloyed rod;

(2) Electrode 2 was mineral coated and carried 0.40 per cent molybdenum;

(4) Electrode 3 was cellulose coated, carrying the same amount of molybdenum and somewhat higher carbon, 0.13 per cent, as against 0.08 for the other two.

Table 1  
SPECIFICATIONS AND ANALYSES OF STEELS USED IN INVESTIGATION

| Steel  | Type   | Specification      | C,<br>% | Si,<br>% | Mn,<br>% | P,<br>% | S,<br>% | Mo,<br>% | Ni,<br>% | Cr,<br>% |
|--------|--------|--------------------|---------|----------|----------|---------|---------|----------|----------|----------|
| CC25   | cast   | ASTM A216-39T WCA  | 0.23    | 0.38     | 0.66     | 0.028   | 0.028   | ...      | ...      | ...      |
| CCM25  | cast   | ASTM A217-39T WC1  | 0.27    | 0.40     | 0.70     | 0.033   | 0.029   | 0.50     | 0.10     | 0.03     |
| CCM35  | cast   | ASTM A157-39 C1    | 0.38    | 0.46     | 0.66     | 0.028   | 0.031   | 0.48     | ...      | ...      |
| CNCM25 | cast   | ASTM A217-39T WC4  | 0.26    | 0.30     | 0.47     | 0.029   | 0.029   | 0.37     | 0.87     | 0.50     |
| WCM15  | rolled | ASTM A206-39T P1   | 0.19    | 0.14     | 0.65     | 0.010   | 0.023   | 0.41     | ...      | ...      |
| WCM25  | rolled | ASTM A182-39 F1    | 0.27    | 0.20     | 0.48     | 0.009   | 0.048   | 0.41     | ...      | ...      |
| WC40   | rolled | SAE 1040           | 0.41    | 0.19     | 0.75     | 0.013   | 0.047   | ...      | ...      | ...      |
| *WSS   | rolled | Type 416 Stainless | 0.12    | ...      | ...      | ...     | ...     | 0.24     | ...      | 11.74    |

\* Not considered a welding grade.

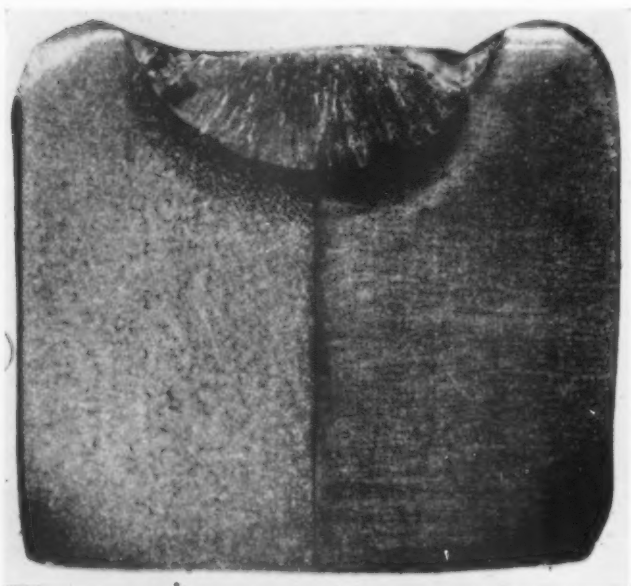


FIG. 4—MACROGRAPH OF STEEL CC25 WELDED TO STEEL WSS WITH ELECTRODE 1. BEGINNING OF WELD. NO PREHEAT. MAGNIFICATION: X4.

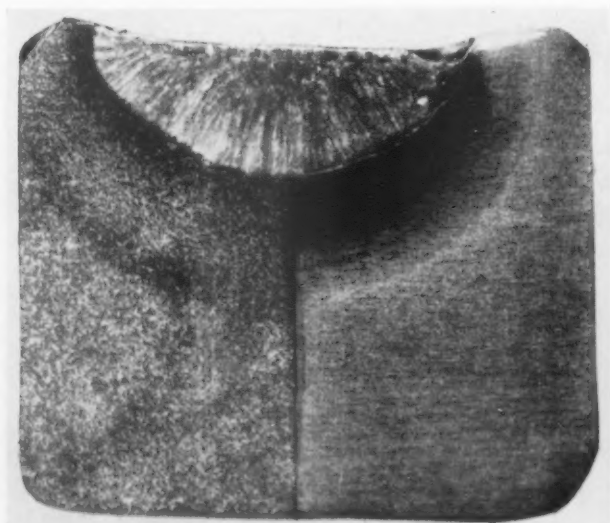


FIG. 5—MACROGRAPH OF STEEL CC25 WELDED TO STEEL WSS WITH ELECTRODE 1. TAKEN AT END OF WELD, THREE-QUARTERS OF THE WAY AROUND THE BAR. NO PREHEAT. MAGNIFICATION: X4.

31. In Fig. 4, a macrograph of steel CC25 welded to steel WSS with electrode No. 1 beginning of weld with no preheat, the columnar crystals of the weld metal and the weld-affected regions of the base metals are readily apparent. As the initial magnification of this photograph is 4 x, the etching effect indicates quite clearly that the base metal  $\frac{1}{8}$ -in. from the weld interface was just heated to the critical temperature. How the depth of this affected zone is altered by the temperature, is shown in Fig. 5, taken at the end of the weld of this same sample three-quarters of the way around the bar. As welding is carried-out, the whole sample increases in temperature and the equivalent of an automatic preheat is found. The difference of hardenability of the two bars is shown by the depths of the affected zones in Fig. 5. The temperature readings of both bars at this position were practically the same, yet the depth of the affected region of the casting—to the left—is seen to be greater than in the forging on the right.

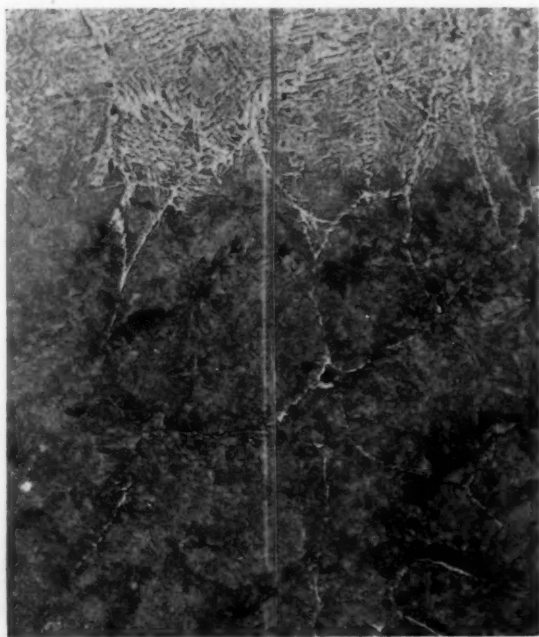


FIG. 6—STRUCTURE OF ROLLED STEEL WC40 WHICH WAS WELDED TO STEEL CC25 AFTER THE WELD AREA WAS PREHEATED TO 300°F. THE LINE THROUGH THE MIDDLE IS A NEEDLE SCRATCH USED FOR IDENTIFICATION PURPOSES. WELD METAL, ELECTRODE 1, IS SHOWN AT THE TOP OF THE MICROGRAPH; BASE METAL BELOW. MAGNIFICATION: X100.

32. These photographs illustrate how the samples were taken. A photomicrographic survey was made along lines perpendicular to the weld interface and at an angle of about  $30^\circ$  to the butt joint. The micrographs were made 0.08-in. apart and were followed with the making of hardness tests of the same spacing using the Rockwell "D" (Brale 100 kg) scale. The hardness readings were thus keyed directly to the micrographic structures.

#### GRAIN SIZE DEVELOPED IN AFFECTED ZONE

33. To illustrate the most extreme case of grain coarsening first, in order to be most familiar with the way the structures will appear, Fig. 6 shows the structure of steel WC40 which was welded to steel CC25 after the weld area was preheated to  $300^\circ\text{F}$ . The line through the middle is a needle scratch on the sample used for reference purposes. The weld-metal, electrode 1, is shown at the top of the photograph; the base metal below. The grain size is coarser than No. 1 A.S.T.M. Grain refinement is quite evident 0.08-in. away from the interface, Fig. 7. At 0.16-in. from the interface, the somewhat coarse original structure is again regained, Fig. 8, and in this photograph may be seen stages of refinement within the pearlitic areas of steel which just exceeded the critical temperature. A horizontal line about two-thirds of the way down the picture would just about define the limit of metal which had been heated above the critical.

34. In Fig. 9, the structure of steel CC25 in the adjoining portion of the sample of this same weld is shown. The grain size here is finer, possibly because of a finer initial structure. Nevertheless, the structures shown in both Figs. 6 and 9 are exceedingly coarse and would probably show a very low impact value, an undesirable condition.

35. Fig. 10 shows the structure of the CC25 steel which resulted from welding the same combination as above but without preheat. The structure, while coarse, is nevertheless considerably finer than the structure of Fig. 9, indicating that preheating often greatly augments coarsening tendencies. Even without preheat, coarse structures develop in these straight carbon steels and, while they are considered of welding grade, considerable caution must be exercised to limit this coarsening. Preheating should be used with care and probably the second bead should not be laid until time has been given for cooling of the first.

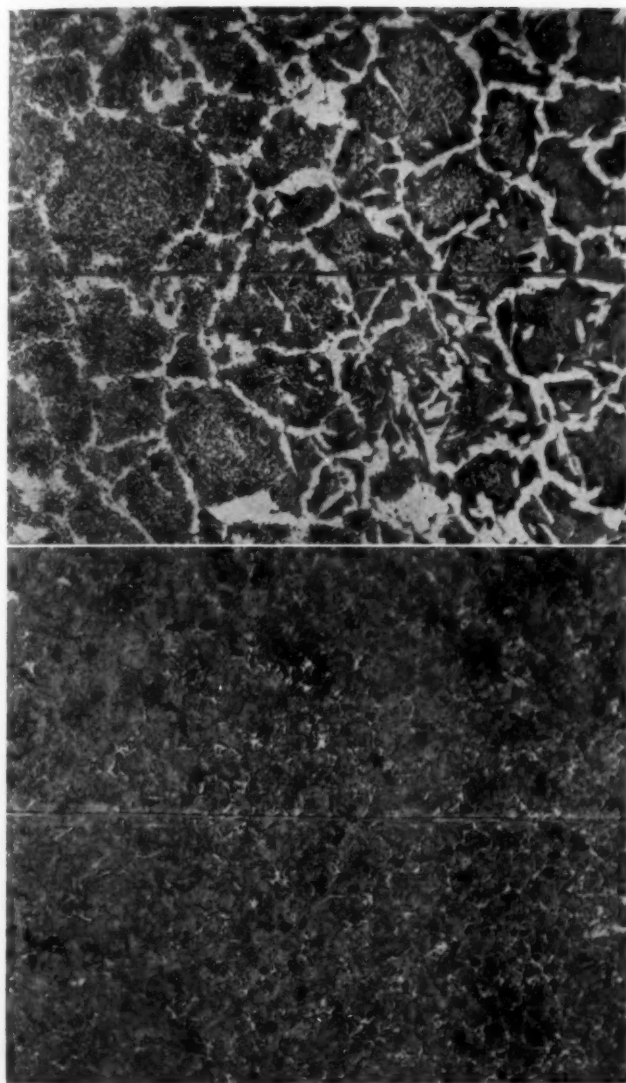


FIG. 7.—LEFT—SAME AS FIG. 6 BUT 0.08-IN. FROM JUNCTION. MAGNIFICATION: X100. FIG. 8—RIGHT—SAME AS FIG. 6 BUT 0.16-IN. FROM JUNCTION. MAGNIFICATION: X100.



FIG. 9—STRUCTURE OF STEEL CC25 IN THE ADJOINING SECTION OF THE SAMPLE OF THE WELD SHOWN IN FIGS. 6, 7 AND 8. MAGNIFICATION:  $\times 100$ .



FIG. 10—STRUCTURE OF STEEL CC25 IN A WELD USING THE SAME MATERIALS AS USED IN THE WELD SHOWN IN FIGS. 6, 7, 8 AND 9, BUT NOT PREHEATED. MAGNIFICATION:  $\times 100$ .

*Grain Coarsening Is Property of Steel*

36. That grain coarsening tendency is a property of the steel, is well indicated in Fig. 11, steel CCM25 welded with electrode 2, using a preheat of 400°F. The weld junction is to be seen just above the horizontal scratch. Even with this higher preheat, the grain size appears no larger than No. 2. The union of weld-metal and base-metal is so good that the junction is scarcely distinguishable.

37. Steel CNCM25, a carbon-molybdenum steel with small additions of nickel and chromium, likewise illustrates this behaviour in Fig. 12, welded with electrode 2 with a 600°F. preheat. The weld interface lies a little above the center of the photograph but can scarcely be detected at this magnification. The grain size of the base metal lies between No. 3 and No. 4. From these illustrations, it appears that small amounts of these alloying elements make the steels relatively insensitive so far as coarsening is concerned.

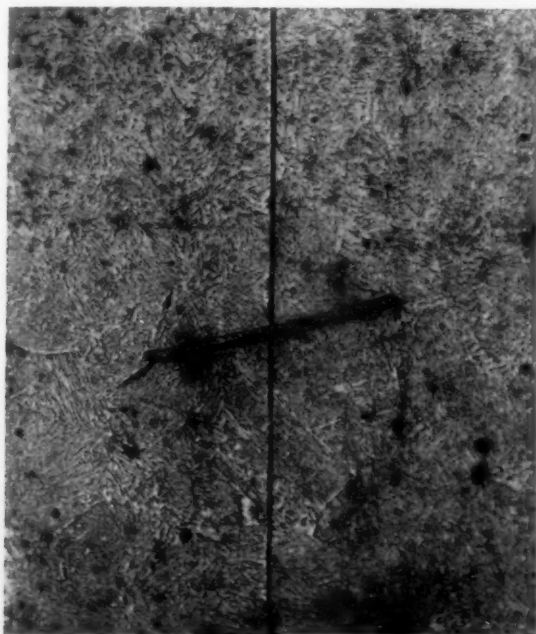


FIG. 11—STRUCTURE OF STEEL CCM25 WELDED WITH ELECTRODE 2, USING A PREHEAT OF 400°F. MAGNIFICATION: X100.

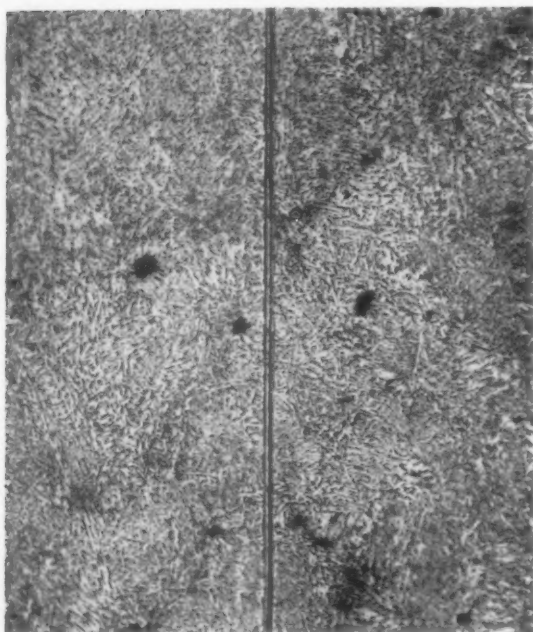


FIG. 12—STRUCTURE OF STEEL CNCM25 WELDED WITH ELECTRODE 2, USING A 609°F. PREHEAT.  
MAGNIFICATION: X100.

38. Grain coarsening must be considered when a tough, ductile, high-strength weld is to be obtained. The tendency toward coarsening is seldom kept in mind, since it is only one of many problems confronting the welder and is, perhaps, the most time consuming problem from a testing viewpoint. It may be possible that fracture tests will give an indication of this property, although the region of coarsening is very narrow.

#### *Possible Reasons for Grain Coarsening Properties*

39. Table 2 lists the grain coarsening tendencies of the steels investigated and what appears to be the maximum allowable preheat. From this table, both cast and rolled carbon steels show bad coarsening. In comparison of the two carbon-molybdenum steels, CCM25 and WCM25, of much the same composition, while both show coarsening at moderate preheating temperatures, the rolled steel shows worse than the cast and in the lower carbon steel WCM15, the coarsening tendency is worse. The original structures of the three steels are quite similar in size, distribution and general appearance.

Table 2\*

COARSENING TENDENCIES AND MAXIMUM PREHEATING TEMPERATURES  
OF STEELS INVESTIGATED

| <i>Steel</i> | <i>Coarsening Tendency</i> | <i>Maximum Preheating Temperature, °F.</i> |
|--------------|----------------------------|--|
| CC25         | Marked                     | Room temp.                                 |
| CCM25        | Appreciable                | 200  |
| CCM35        | Appreciable                | 200  |
| CNCM25       | Negligible                 | 600  |
| WCM15        | Marked                     | 200  |
| WCM25        | Marked?                    | 200  |
| WC40         | Very bad                   | Room temp.                                 |

\* Compare with Table 3.

40. There is, thus, little doubt that the difference of behaviour of the rolled steels is due to the steel manufacturing process, for both have had heat treatment after rolling. Both showed ferrite banding to a marked degree.

41. The cast steels showed increased coarsening with increasing carbon, and decreased coarsening with increasing alloy content. All cast steels were aluminum killed.

42. The rolled steels, being bought commercially, it was not possible to ascertain their full history. Such rolled steels usually are fully killed also, but the suggestion seems to be that the samples used were not, as there was either little or none of the usual grain refinement due to the action of aluminum.

43. Whatever may be the cause, if these steels are representative of commercial practice (and since they are within commercial specifications, there is no reason to suppose that they are not), greater care must be used in welding and lower limits of preheat must be prescribed for the wrought steels than in cast steels of equivalent analysis or more adequate specifications should be devised. That other factors may influence this maximum preheating temperature limit, will be seen in the following sections.

## HARD STRUCTURES DEVELOPED IN AFFECTED ZONE

44. As already stated, hard structures may result in the base-metal as a consequence of the very rapid abstraction of heat. Fig. 10 shows traces of martensite in straight carbon steel CC25 just



FIG. 13—STRUCTURE OF STEEL WC40, USED AS A PART OF THE SAME WELD, SECTIONS OF WHICH ARE SHOWN IN FIGS. 6, 7 AND 8, WHICH SHOWS BOTH MARTENSITE AND NODULAR TROOSTITE. NO PREHEATING. MAGNIFICATION:  $\times 100$ .

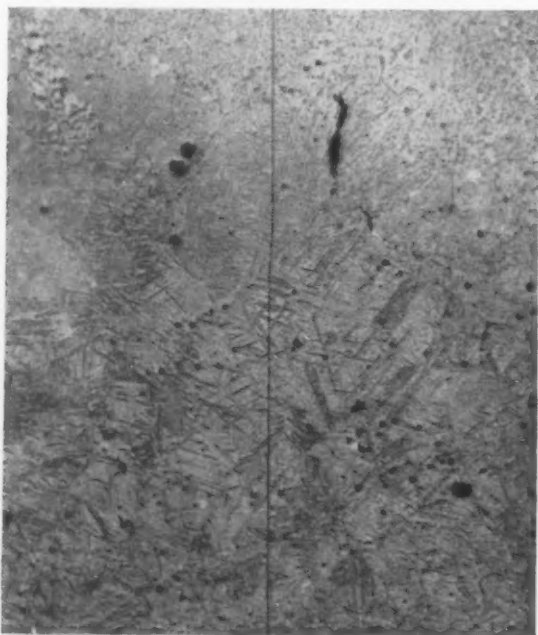
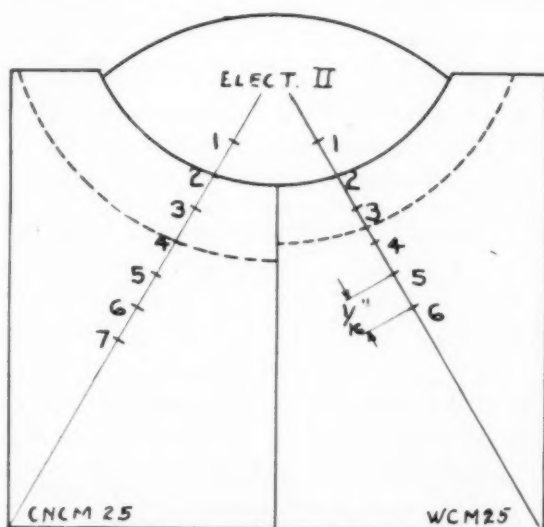


FIG. 14—STRUCTURE OF STEEL CNCM25, WELDED TO STEEL WCM25 WITHOUT PREHEATING. SHOWS A MARTENSITIC STRUCTURE IN A ZONE 0.020-IN. DEEP. MAGNIFICATION:  $\times 100$ .

under the interface, although it is here broken down. In Fig. 13, steel WC40, which formed part of this same weld, shows both martensite and nodular troostite. Compare these photographs with



TEST II, POSITION I  
NO PREHEAT

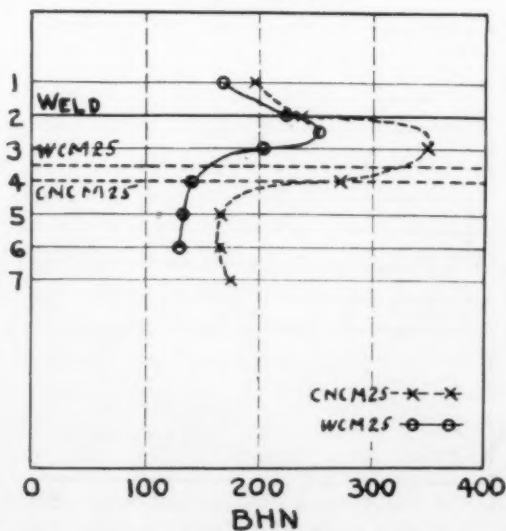


FIG. 15—LOCATION OF HARDNESS TESTS AND HARDNESSES DEVELOPED IN STEEL CNCM25 WELDED TO STEEL WCM25 WITHOUT PREHEAT AT THE BEGINNING OF WELD.

Figs. 6 and 9, which are of the same combination welded with a 300°F. preheat. No trace of martensite is left nor can it be if we consider the fact that martensite is not the end product of the austenite transformation in these steels at temperatures above 300°F., and the act of welding will raise the temperature of the base steels considerably above the preheating temperature.

45. A study of the "S"-curves, derived through studies of the subcritical transformations of the various steels, will show the temperature of preheating necessary to completely avoid hard structural formations under the most severe conditions of welding. In Fig. 14, cast steel CNCM25, welded without preheat to steel WCM25, is shown to develop a martensitic structure in a band about 2-in. deep, or, since the original magnification was  $\times 100$ , a zone 0.020-in. deep.

46. In Fig. 15, the hardness measurements across this weld are given. At the top, a sketch is given showing the way the hardness indentations were made; the dotted lines show the limit of the affected zone as revealed by etching. At the bottom, the hardness values, as converted to Brinell, are plotted against the distance from the weld interface. A high hardness of 350 BHN. is shown for the cast steel, this hardness being shown 1/16-in. from the

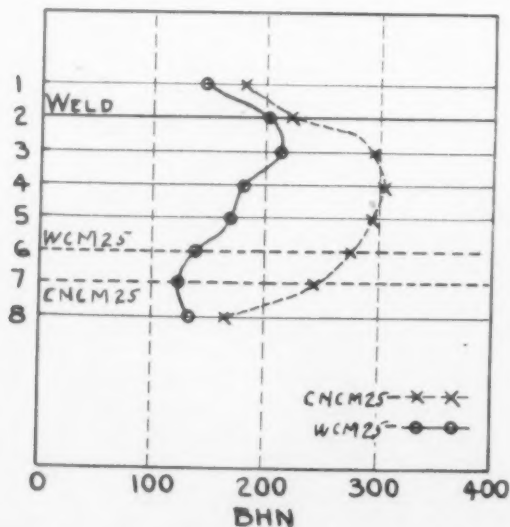


FIG. 16—HARDNESS DEVELOPED IN STEEL CNCM25 WELDED TO STEEL WCM25 WITHOUT PREHEAT AT THE END OF THE WELD.

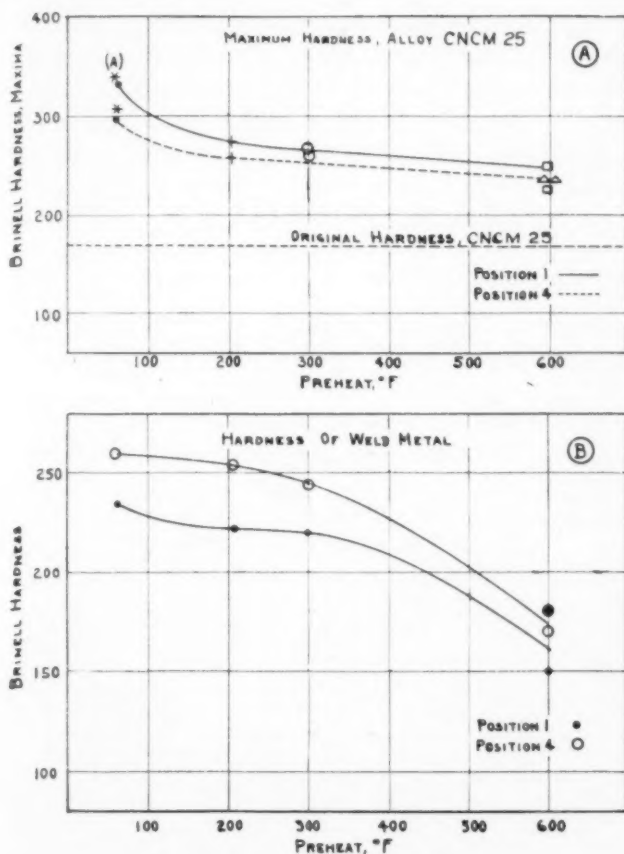


FIG. 17—HARDNESS OF STEEL CNM25.

interface. At the end of welding in this sample, the maximum hardness had dropped to about 300 BHN. as shown in Fig. 16, but it may seem that, although the hardness has dropped slightly, the hardening extends much deeper.

47. The effect of preheating on the hardness developed in this alloy, and also on the weld-metal applied to it, is shown in Fig. 17. Position 1 in these diagrams refers to the beginning of welding and position 4 to the end. A preheat as low as 200°F. is nearly as effective as a 600°F. preheat in reducing the hardness.

#### *Hardness Tests Not Satisfactory*

48. The use of the hardness tester has not, in these tests, proved especially satisfactory in determining whether or not mar-

tensite has been formed. It was shown in Figs. 10 and 13 that a martensitic or troosto-martensitic structure is developed in the straight carbon steels welded without preheat. In Fig. 18, the results of a hardness survey with different preheating temperatures is given for steel WC40. At position 1, a slightly higher hardness is found with a 300°F. preheat than with no preheat. Yet Fig. 13 shows a structure of this steel which would be expected to be very much harder than the structure shown in Fig. 6, of the same steel, welded with a preheat of 300°F.

49. It is evident that erroneous results were obtained in the hardness test and it appears that the cause is not hard to find. The

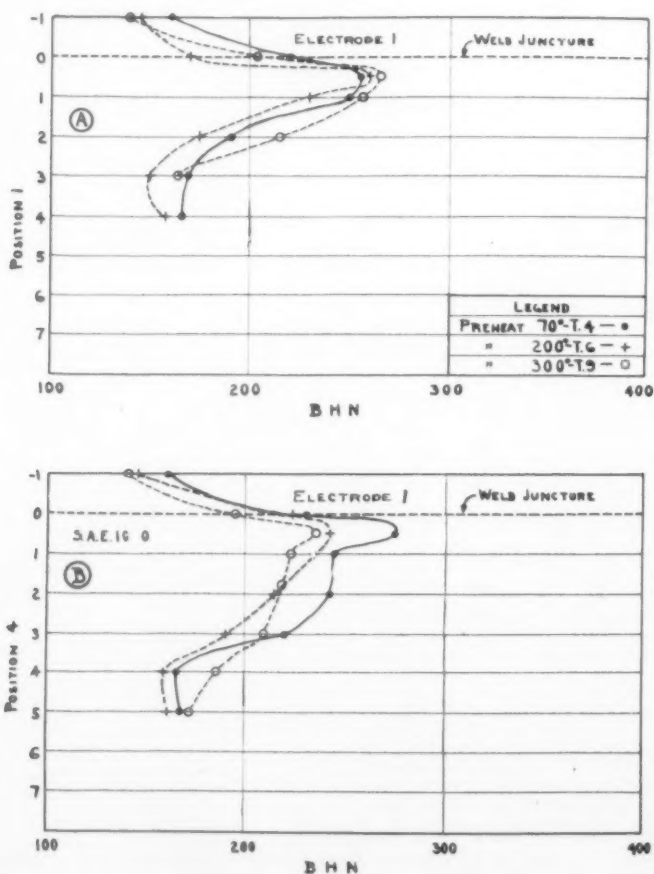


FIG. 18—HARDNESS OF STEEL WC40 WITH ELECTRODE 1.

martensitic zone is quite narrow and the diameter of the Brale impression is large in comparison. Thus, not only will hard structure contribute to the hardness reading, but also the softer base-metal and weld-metal back of the hard zone. This assumes that the Brale has not, in the first place, slid off the martensitic ridge into the softer backing material. In either case, a deceptively low hardness reading would result. The hardness of brine-quenched samples of the cast steels ran well in excess of 400 BHN. and their structures showed fully martensitic. It is thus felt to be quite evident that the highest actual hardness developed in these welds was not measured, the discrepancy in certain cases amounting to at least as much as 100 BHN.

50. On the basis of microstructure and the hardness readings so far as they can be trusted, Table 3 has been prepared giving the minimum preheat necessary to prevent the formation of hard structures. From this table, it appears that the hardening of these steels fairly well follows the carbon content. According to the carbon, the steels can be divided into three groups, as follows:

- Group I WCM15 — (carbon under 0.20 per cent)
- Group II { CC25 — (carbon above 0.22 and below 0.28 per cent)  
CCM25  
CNCM25  
WCM25
- Group III { CCM35 — (carbon 0.35 per cent or over)  
WC40

**Table 3**

MINIMUM PREHEATING TEMPERATURES NECESSARY TO PREVENT  
FORMATION OF HARD STRUCTURES

| <i>Steel</i> | <i>Preheat Minimum, °F.</i> |
|--------------|-----------------------------|
| CC25         | 200                         |
| CCM25        | 200                         |
| CCM35        | 300                         |
| CNCM25       | 300                         |
| WCM15        | Room temp.                  |
| WCM25        | 200                         |
| WC40         | 300                         |

It will be seen in Table 3 that some of the temperatures necessary to avoid development of martensitic structures are higher than the

temperature limits fixed in Table 2 for grain coarsening. Of the two evils, martensitic structure is the worse, and must be prevented at the expense of coarsening.

51. With this in mind, Table 4 has been prepared according to carbon contents and changing the temperature limits according to the need. It should be remembered that these results are derived from data on very severe welding tests, single bead on heavy sections, and hence, insofar as hardening is concerned, are on the safe or conservative side.

**Table 4**  
RANGE OF PREHEATING TEMPERATURES TO PRODUCE BEST  
WELD STRUCTURES

| Group | Steel  | Preheat, Min., °F. | Preheat, Max., °F. | Coarsening Tendency |
|-------|--------|--------------------|--------------------|---------------------|
| 1     | WCM15  | Room temp.         | 300                | Marked              |
| 2     | CC25   | 200                | 400                | Marked              |
| 2     | CCM25  | 200                | 400                | Appreciable         |
| 2     | CNCM25 | 300                | 600                | Negligible          |
| 2     | WCM25  | 200                | 400                | Marked?             |
| 3     | CCM35  | 300                | 400                | Appreciable         |
| 3     | WC40   | 300                | 350                | Very bad            |

#### EQUIVALENCE OF HEAT-TREATING EFFECTS IN WELDING

52. It is of interest to examine the structures from the point of view of the rate at which heat is abstracted from the material welded without preheat. In the lowest carbon steel examined, steel WCM15, no martensite could be found nor was there evidence of pre-existent martensite which may have been drawn by the heating resulting from further laying of the weld bead. In the steels of Group 2, there was evidence of pre-existent martensite in all but steel CNCM25. This steel showed a trace of martensite retained. In the steels of Group 3, both showed martensite retained, steel WC40 showing a slightly less than martensitic condition from the presence of troostite.

53. In comparative quenching experiments on samples of the same cast steels, all showed full martensitic structures with hardnesses approximately 450 BHN. when quenched in either brine or oil. In small sections, steel CNCM25 showed martensite on air

quenching but heavier sections did not. According to the thermocouple record, the maximum temperature reached by the backing base-metal, where first welded, at the completion of welding, was 487°F. in the case of steel CNCM25 and 350°F. in the case of the SAE 1040.

54. Brine quenched samples on steel CCM25 were reheated for one hour at 500 and 700°F. The sample heated at 500°F. showed a drop in hardness from 440 to 400 BHN. The sample etched more rapidly than in the as quenched condition but retained its acicular martensitic appearance. With a 700°F. draw, the hardness dropped to 229 BHN. and, while there were still traces of the martensitic pattern, the break down was quite apparent.

55. The time at which the weld samples stayed at temperature after welding was short for on finishing, they were immediately pulled out of the line and were subjected to normal air cooling. Hence, if martensite were formed in any of the lower carbon steels, it is felt that traces would still be present in the microstructure.

56. No such traces were found in steel WCM15 as already remarked, and in steels CC25 and CCM25, the evidences of martensite were not as pronounced as in the brine quenched samples drawn at higher temperatures than those to which they were subjected. It would thus appear that, even in the severe conditions here employed in welding, the quenching action was not as great as in an oil quench at room temperature. It was, however, faster than a quench in air.

57. With the rise in temperature of the base-metal or in the temperature contributed by preheating, the question raises itself whether or not an austempering process would be expected to occur.

58. In the steels welded in this experimental work, a definite statement in this regard cannot be made. However certain structures did appear which, as a result of other evidence, might be attributed to this cause. In another experimental weld, a quite similar structure was found. A flat plate 3/16-in. thick was machined from a casting of steel CCM25. This plate, 8-in. square, was supported on two bricks and a bead of electrode 2 was deposited for a length of one-in. in the center unsupported area. The weld was cut out, sectioned and polished. In Fig. 19, the structure is shown at the weld interface, weld-metal being at the top.



FIG. 19—STRUCTURE OF WELD INTERFACE WITH WELD METAL AT TOP IN STEEL CCM25 PLATE ON WHICH A BEAD OF ELECTRODE 2 WAS DEPOSITED. MAGNIFICATION: X500.

59. The cast steel is seen to be largely martensitic, except as affected by diffusion of the weld-metal. However, out at the edge of the affected zone, the structure is found which is illustrated in Fig. 20. The unaffected metal is shown to the left. In Fig. 21, this zone is shown at higher magnification. In the dark colored patches, which etched yellow with picral, a faint acicular structure can be seen. The change in appearance of this structure is shown in Fig. 22, 0.08 ins. nearer the weld.

60. This latter structure is very similar in appearance to that found by Davenport<sup>3</sup> in SAE 4140 steel when such steel transforms isothermally at temperatures about 1000°F. Davenport described such a structure tentatively as "acicular ferrite ( $x$ )," designating it as a transitional form between lamellar and acicular structures. The areas we have found in steel CCM25 are much larger than those described by Davenport but there is little doubt in the authors' minds that they are identical.

61. In Fig. 23, the structure of steel CCM25 welded at a pre-heat of 400°F. is shown representing an area near the edge of the affected zone, a distance of 0.37-in. from the weld interface. This

<sup>3</sup> Davenport, E. S., "Isothermal Transformation in Steels," TRANSACTIONS, American Society for Metals, vol. 27, pp. 837-886 (1939).

structure is so similar in appearance and etching effect to that found in the experimental plate weld that it is difficult to believe that the two are not closely related. A maximum temperature of

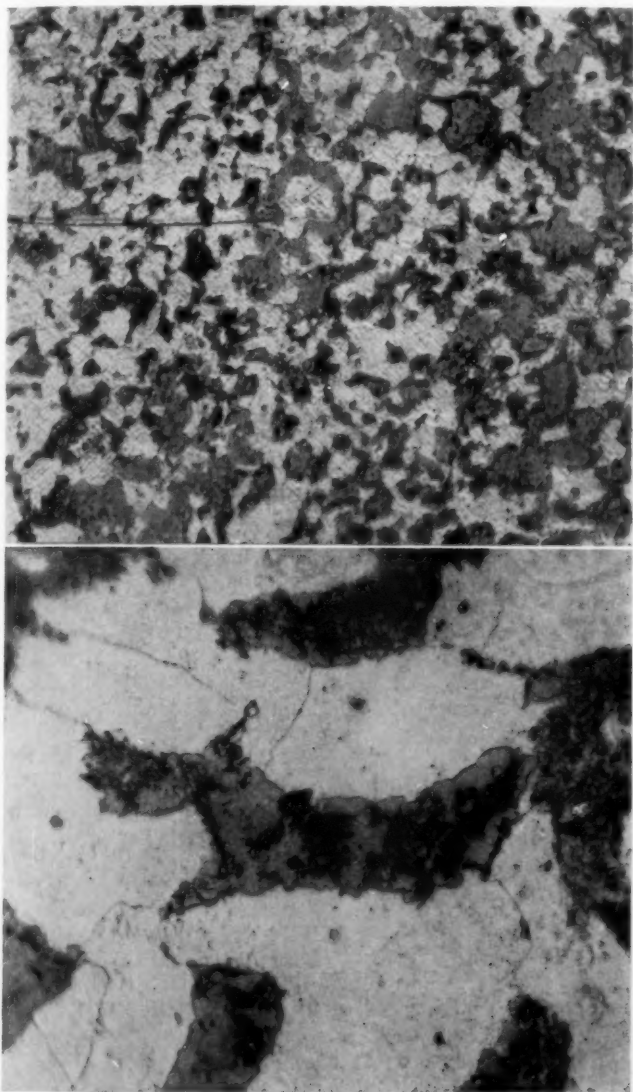


FIG. 20—TOP—SAME WELD AS IN FIG. 19. STRUCTURE AT EDGE OF AFFECTED ZONE. MAGNIFICATION:  $\times 100$ . FIG. 21—BOTTOM—SAME ZONE AS IN FIG. 20 BUT WITH MAGNIFICATION OF  $\times 1000$ .

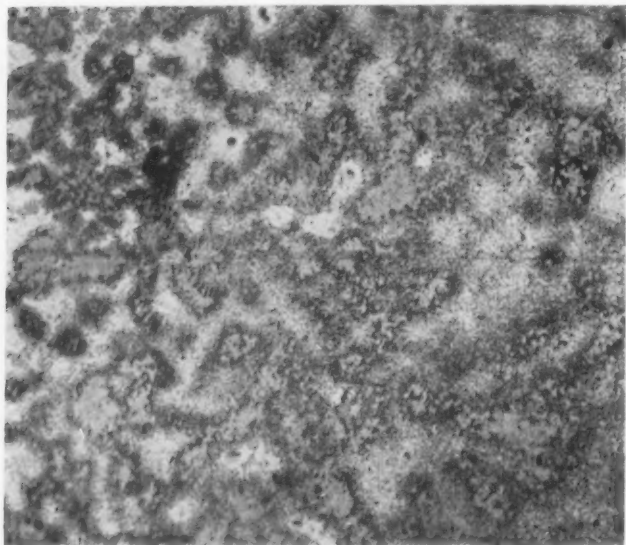


FIG. 22—CHANGE IN STRUCTURE OF FIG. 21 AT A POINT 0.08-IN. NEARER THE WELD. MAGNIFICATION: X100.

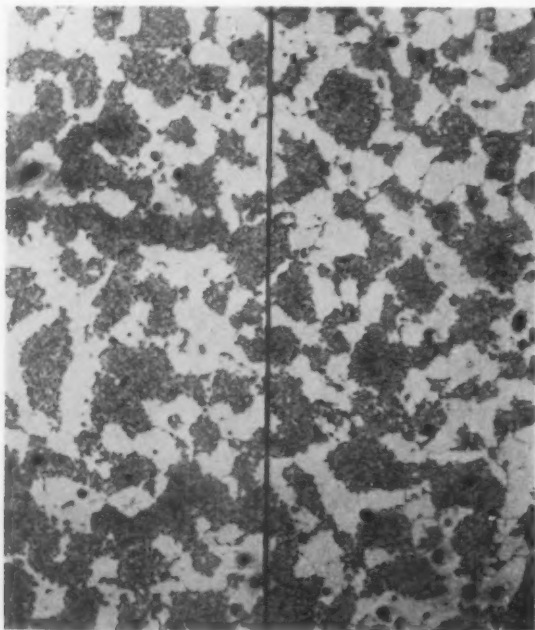


FIG. 23—STRUCTURE OF STEEL CCM25 WELDED AT A PREHEAT OF 400°F. THIS STRUCTURE IS THAT OF AN AREA NEAR THE EDGE OF THE AFFECTED ZONE AT A DISTANCE OF 0.37-IN. FROM THE WELD INTERFACE, WELDED WITH ELECTRODE 2. MAGNIFICATION: X100.

810°F. was recorded on this weld, a temperature bordering on that where the ( $\alpha$ ) structure would be produced by subcritical transformation.

62. Complete metallographic data on these transformation processes are not available for the steels used in this research and it is entirely possible that other structures present in the welds will find their origin in this cause. When these data become available, it will be of interest to re-examine the weld structures to see if the austempering process is not more extensive.

#### BURNING-IN DURING WELDING

63. It was found in the preheating experiments that with increasing preheating temperatures, the depth of melting became quite pronounced. In Fig. 24, an example of this burning is shown for steel CCM25 welded with a preheat of 600°F. The dotted line shows the original contour of the machined groove. Melting has taken place to a depth of 0.14-in. below the depth of the groove. The burning-in follows the temperature of the base metal fairly closely, and without regard for the type of material. In each case, it was more pronounced in position 4 than in position 1, and worst with the highest preheats.

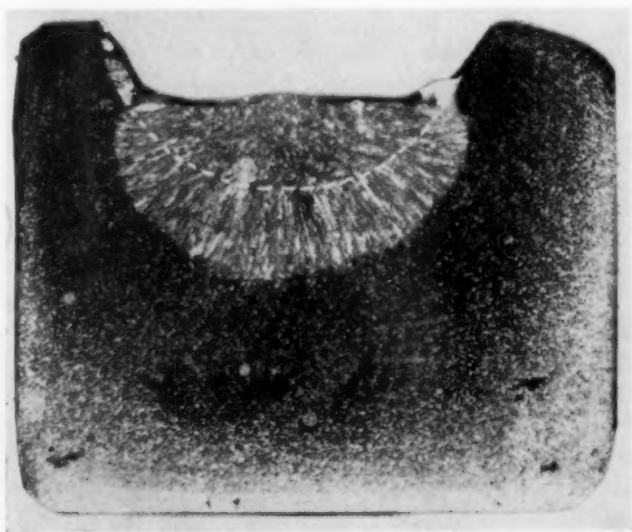


FIG. 24—STEEL CCM25 WELDED WITH A PREHEAT OF 600°F. SHOWING DEPTH OF MELTING.

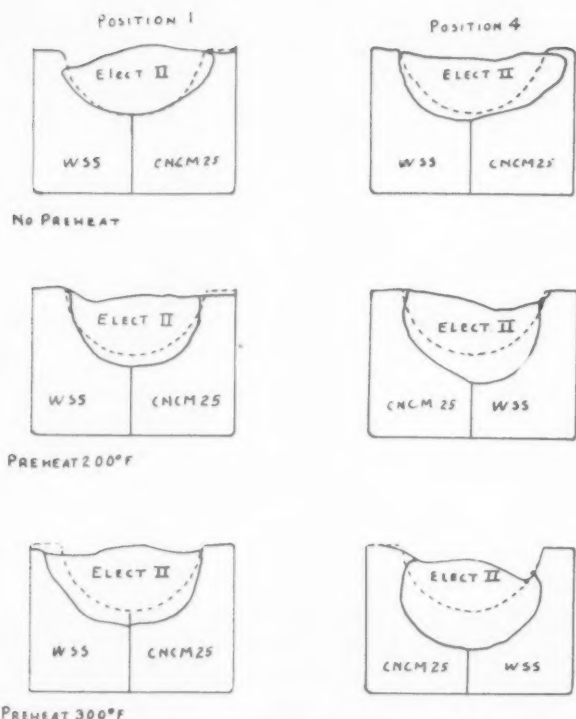


FIG. 25—EFFECT OF "BURN-IN" IN STEEL CNCM25 WELDED TO STEEL WSS WITH DIFFERENT PREHEATS.

64. This is more clearly brought out in Fig. 25 in which tracings of the macrographs of steel CNCM25 welded to steel WSS with electrode 2 are given, showing the effects of fairly low-temperature preheats. Without preheat, there is a certain amount of lateral melting but penetration into the base-metal is slight. With a preheat of 200°F., a slight amount of melting is shown at position 1, greater in position 4. From the other results where the burning is more uniform, it would appear that the greater burning of steel WSS with this preheat is entirely due to the method of handling the are during the welding. With a 300°F. preheat, burning is quite uniform all the way around at position 1. In position 4, it is very deep, nearly, though not quite as deep as shown in Fig. 24. With the exception of position 4 with a 200°F. preheat, the penetration was practically the same for both the CNCM25 and the WSS steels.

65. This penetration in all probability follows only the melting point and is independent of alloy content. The arc temperature is so much above the melting point of the steel, regardless of type, that small variations of the melting point of the two steels to be joined has little effect on the total amount of burn-in. With higher preheats, a greater amount of metal is capable of passing the melting point from heating of the arc.

66. As a result of this melting, great care must be used in the welding of thin-walled material when a preheat becomes necessary. This will be particularly true for fillet and bead welds but, even for butt welds, there may be excessive root penetration and breakdown of side walls. If a strapped butt weld is made, burning through of the strap must be guarded against.

#### SUMMARY

67. The general principles involved in the alteration of the structure of steel as a consequence of welding have been briefly reviewed and the structures developed in certain well-known grades of cast steel when welded to common wrought steels have been correlated with these principles. How the structure of a steel is affected by its hardenability and the effects of preheating on the structure have been described.

68. A trend, in some quarters, to attempt to discredit the safe weldability of steels with carbon contents usually found in casting grades, may have raised questions in the minds of foundrymen and castings users as to the weldability of steel castings in general. From this work, however, it would seem that such discrediting is unwarranted. The structures developed in steels of 0.25 per cent carbon were fully as good as in the steel of 0.15 per cent carbon and, so far as granulation was concerned, the wrought steel of 0.15 per cent carbon was inferior.

69. The blending of weld-metal and base-metal was exceptionally good in the case of the cast CCM25 and CNCM25 steels. There was little coarsening even at high preheating temperatures and martensitic structures could be prevented without difficulty. With good welding practice, sound, high-strength welds could be made with any of these cast steels, including those up to say 0.35 per cent carbon.

70. None of the steels showed a martensitic or near martensitic structure at position 4 (end of weld bead) even with no preheat. The automatic preheating of the preceding weld metal layer and the conductivity of the base metal prevented formation of a hardened layer. At position 1 (beginning of weld) and no preheat, a definite martensitic condition was found with steels CCM35 and WC40. A very slight layer was found in steel CNCM25 and an approach to a martensitic condition was found in steels CCM25 and WCM25 and also possibly in very small areas in steel CC25. Steel WCM15 showed no evidence of a hard structure in any location.

71. A preheat of 300°F. would appear to be sufficient to avoid the possibility of martensitic formation on the first part of the first bead in all of the steels examined. Localized heating would probably be sufficient for materials of the class 0.25—0.30 per cent carbon since, once started, the bead "self-draws," as in position 4. Moreover, the laying of a second bead would temper the hard spots in the first part of the first bead.

72. None of the cast steels showed as marked tendency toward grain-coarsening as did the wrought steels examined. The plain carbon cast steel CC25 was most marked of the cast steels in its coarsening tendency but, even so, was very much better in this regard than any of the wrought steels. Small amounts of alloying constituents increased the resistance to coarsening, the coarsening tendency in steel CNCM25 being negligible even with high preheating temperatures.

73. Burning-in of the base metal is less a problem than the foregoing for the foundryman. It should be guarded against, and the influence of design should be carefully considered. Excessive melting or burning-in seemingly is only dependent on melting points and not otherwise on composition of the base-metal. It, of course, is affected by operating conditions of torch or arc and often may be alleviated wholly or in part by suitable manipulation.

74. In the testing of welds for evaluation of the alterations of structure, it is a conclusion of the authors that, aside from exhaustive tests of ductility and impact resistance, the most reliable method is microscopy. With a penetration hardness tester, even a small penetrator is likely to miss the thin, hard, brittle layers that may be formed. When these layers are known to be present, they

may be so localized and small that the penetrator either straddles the layer or may slide off to one side. The penetration hardness test gives little or no evidence of coarsening. A "scratch hardness" tester or microcharacter might be quite useful. For a measurement of coarsening, in many cases the coarsened region is too narrow to be analyzed with a fracture test.

75. With the samples available, microscopy proved highly useful and reliable. It may be said that physical mensuration (as by tensile-ductility, impact tests, fatigue test) is to be preferred. There is some merit to this argument, and in our opinion such methods, backed up by microscopy, would be very useful. However, the general effects of various microstructures are well known and accurate qualitative analysis is not difficult. A good microstructure insures good physical properties, a bad one is always dangerous.

76. It is hoped that this work will help to clarify some of the misunderstandings that have arisen and that it will stimulate the foundryman, whose steels are to be subjected to a welding operation, to more extensive study and greater co-operation with the welding engineer. It should suggest to the foundryman that his product, intelligently used, is better adapted to welding uses than some trade opinions might lead one to believe.

#### ACKNOWLEDGMENTS

77. The authors hereby extend their thanks to the Lunkensheimer Co. whose policies and backing have made this investigation possible.

## DISCUSSION

*In absence of the authors, the paper was presented by C. W. Briggs, Steel Founders' Society of America, Cleveland, O.*

*Presiding: H. D. PHILLIPS, Lebanon Steel Foundry, Lebanon, Pa.*

CHAIRMAN PHILLIPS: The investigation definitely explodes the theory that cast steel lacks the weldability of the rolled products.

J. A. DUMA<sup>1</sup>: I would like to know whether the authors say anything about stress relieving. When is it required in the weld or in the casting that has been welded? Navy specifications will allow welding on steel where the carbon content is below 0.25 per cent and a manganese of 0.75 per cent maximum, and require no stress relieving thereafter. If the carbon content happens to be higher, and the analysis a little on the high side, then stress relieving is in order. Have the authors shown when stress relieving is required?

There are many applications aboard ship when a casting cannot be taken out very easily and welding must be done in position, and we do like to dispense with the stress relieving treatment. We have found a way of doing that. If the welding is of a minor type, we use a 25-20 electrode and make a one-pass weld. We find that material that has a high ductility is able to take shrinkage stresses, and it takes a lower amperage to weld, or lay the metal down, and therefore the hardness developed in the heat-affected zone is not very high. That enables us to dodge the stress relief treatment sometimes.

I also notice that cellulose electrodes versus the mineral type are discussed. We found, in welding castings, that the mineral type electrode is superior in that it gives a deposit free from the defect known as "fish-eyes" or "bird-eyes." Cellulose coatings are very apt to give a great many bird-eyes, so we use a mineral coated electrode.

When we limit ourselves that way and stick to the mineral coated rod, we also automatically limit ourselves as to the position. Mineral coated rods usually are not all-position rods. You cannot weld vertically upwards or overhead, and are compelled to weld in a horizontal position at an angle probably 20 to 25 degrees upwards or visa versa, so we utilize the lathes and other positioning instruments, whereupon we place our work and try to carry on welding in that position.

Regarding the maximum Brinell hardness developed in the heat-affected zone and grain size, sometimes we have an alloy steel whose analysis will compel us to use a high perheat to get away from the high hardness in the heat-affected zone. This high heat will coarsen the steel in that area so, though we get away from one evil—maximum hardness, we run into another—grain coarsening. I wonder how the authors determined their optimum preheating temperatures.

<sup>1</sup>Assistant Metallurgist, Norfolk Navy Yard, Portsmouth, Va.

One other thing, it seems to me that every steel has its own characteristic history, its own reaction to heat, depending upon its exact analysis and the way it was made and deoxidized. If you get a certain grain coarsening in the heat-affected zone on the 0.25 per cent carbon steel, that does not mean that you are not going to get grain coarsening in another steel of the same carbon content but which has been made differently. We know that, once the inherent grain size is established, the steel afterwards will react according to its inherent grain size, so analysis alone, or the carbon content alone, does not impose a limit on grain coarsening.

About preparation in welding castings, we have found that beveling the joint to the smallest opening possible is the best way to weld castings; instead of having a 45 degree bevel, or totalling an acute angle of 90 degrees. We like to have a 15 degree bevel angle or total opening of 30 degrees. That automatically limits the amount of weld metal that you are allowed to put into the opening, and the less that you put in and the shorter the distance across the weld, the less shrinkage stress you will encounter and the better the weld will be.

A final comment, in making thick joints (one inch and over) in steel castings, we take recourse to sequence welding. The bottom layer is laid with a very small electrode,  $\frac{1}{8}$ -in. diameter. On top of that is used a  $\frac{1}{2}$ -in. diameter electrode, a little larger in size, requiring a little larger welding current, and thus giving a slightly higher heat input. On top of that will be used  $\frac{3}{8}$ ,  $\frac{1}{4}$ -in. diameter, etc., electrodes. We find the higher heat input by the overlying beads anneals more thoroughly and completely the beads beneath. The smaller that bead beneath and the shallower it is, the easier it is for the top overlying beads to give you 100 per cent recrystallization in the bottom beading. In that way, you will also get higher ductility.

Regarding aluminum killed steels, we make steel under lime-alumina slag with a residual aluminum content of 0.004 or 0.006 per cent, and we have not found any difficulty in welding steels of that aluminum content. Of course, we do not deoxidize our metals with aluminum entirely; we use calcium silicide and ferro-titanium chiefly.

J. J. KANTER<sup>2</sup> (*Written discussion*): A consideration of the cooling transformation of the cast steels which the authors discuss might have some bearing on the question which Mr. Duma raises regarding a criterion for the necessity of stress relieving. Fig. 26 shows dilatometer charts for three of the types of cast steels, which the authors consider—plain carbon steel, of the welding grade WCB, carbon-molybdenum steel, welding grade WC1, and a nickel-chromium-molybdenum steel, representing the maximum alloy contents permissible under A.S.T.M. Specification A217-39T for the welding grade WC4.

In these charts, the transformation ranges are defined by discontinuity in the thermal expansion. In all three examples shown, the steel remains ferritic upon heating until a temperature of 1300 to 1400° F. is

<sup>2</sup>Research Metallurgist, The Crane Co., Chicago.

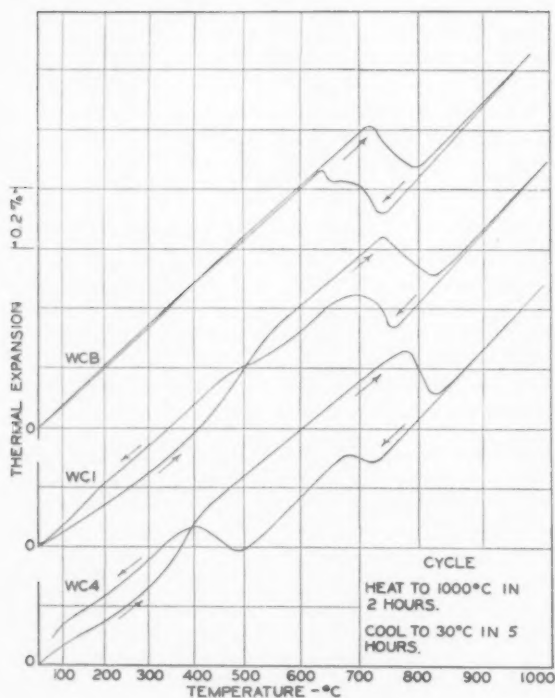


FIG. 26—THERMAL EXPANSION OF THREE GRADES OF STEEL

| Steel       | Grade | C    | Analyses |      |      |      |      |
|-------------|-------|------|----------|------|------|------|------|
|             |       |      | Mn       | Si   | Ni   | Cr   | Mo   |
| Carbon      | WCB   | 0.27 |          | 0.35 | 0.51 | 0.24 | 0.11 |
| Carbon-Moly | WCI   | 0.26 |          | 0.35 | 0.35 | 0.02 | 0.51 |
| Welding     | WC4   | 0.31 | 0.79     | 0.28 | 1.05 | 0.76 | 0.49 |

exceeded, whereupon transformation over a range of about 200°F. to austenite ensues. Upon cooling, the reverse transformation occurs, but not over the same temperature ranges observed during the heating cycle.

The transformations upon cooling, in general, tend to be more "sluggish" than upon heating. In the examples under discussion, a slow cool covering 5 hr. was used. If the cooling transformation has any tendency to be sluggish as far as a welding procedure is concerned, cooling over this period should develop the fact in a dilatometer record.

Plain carbon steels, whether cast or wrought, in general show the well defined cooling transformations found for grade WCB, which reaches completion at a temperature between 1150 and 1200°F. At such a temperature, the steel is still plastic enough to "self relieve" itself of in-

ternal strains caused by the volume increase associated with the austenite-ferrite transformation. Thus, carbon steels are attractive from the welder's standpoint because of their freedom from internal strains.

Carbon molybdenum steel, as exemplified by the curves marked "WC1," undergoes the major portion of the transformation at a high temperature range, but does not completely transform until it has cooled to a temperature below 800°F., which indicates that a stress relieving treatment may sometimes be necessary in welding procedures involving this steel.

In the case of the nickel-chromium-molybdenum, grade WC4 steel, an entirely different transformation character on cooling is observed. For this material, but a small portion of the transformation is completed in the high temperature range. The major portion of the transformation, and accompanying volume increase, takes place while cooling from 900 degrees to 750°F. Thus, this steel is apt to be left with rather considerable internal strains, which necessitate a thorough stress relieving heat treatment for any welded structure fabricated from it.

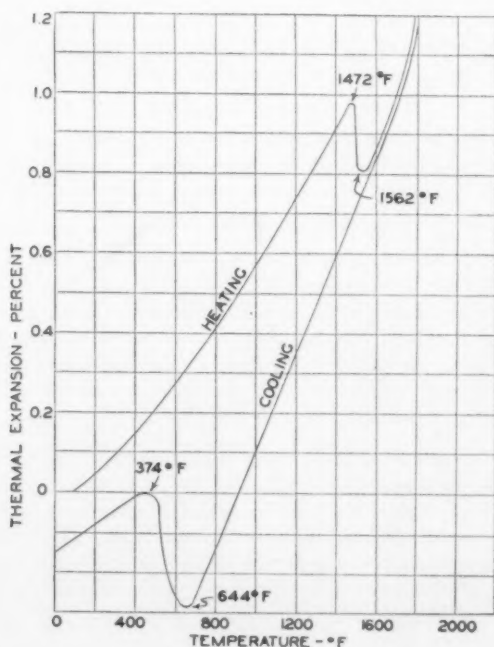


FIG. 27—LINEAR EXPANSION AND CONTRACTION VS. TEMPERATURE ON 12 PER CENT CHROME STEEL.

This WC4 grade was found by the authors to require the highest preheat temperature of the steels, which they investigated, and which of course implies that much greater precaution is needed for welding this material than is required for either grades WCB or WC1. It is of interest to note that the dilatometer character of this steel approaches that of the 12 per cent chromium iron, Fig. 27, which, as the authors note in their Table 1, is "not considered a welding grade." It would, therefore, appear that if grade WC4 is to be considered a welding grade of steel, it should also be understood that it requires much more exacting procedure than the plain carbon, or carbon molybdenum steels.

A. J. SMITH and J. W. BOLTON (*Author's Written Closure*): The writers thank those who contributed to the discussion of their paper, and especially Mr. Briggs who presented it.

As often happens the discussion brought up matters not directly along the lines of the writers' reported work. This is proper and desirable, in many ways. However, it should be noted that the particular issue in the writers' paper is the determination of structures developed in the various steels when exposed to the high temperatures in welding, followed by cooling at varying rates which are dependent upon preheating temperatures.

Welding stresses are another matter, being affected to a considerable degree by the geometry of the castings or part under consideration. Mr. Duma indicated some methods of getting around difficult situations of this sort.

In our test, the bead was laid horizontally, the bars being rotated, and, where comparisons could be made, the mineral coated electrode seemed to give a superior weld. Mr. Briggs points out that the mineral coated rod gives a sounder weld radiographically.

In the paper, temperature limits are given for prevention of coarse grain sizes and for the elimination of hard structures. The optimum pre-heating temperatures given are a compromise between the two. Because of coarsening and of "burning in," preheating should be avoided whenever possible. However, if the steel is air-hardening, just sufficient preheat should be given as to insure a breakdown of the hard material, of course striking a balance between the two undesirable effects.

That the history of a heat of steel is important is quite evident in comparing the coarsening tendencies of the cast and rolled CMo. The analyses are much the same but the rolled variety was much worse in its coarsening tendency than the cast. Conceivably the situation could be reversed, for as experience is gained, it becomes more obvious that steels for elevated temperature service should be "hand tailored" to meet service requirements. This is a very big subject in itself.

Some of the implications of Mr. Kanter's discussion are based upon unsound premises. May we not first state that a reason we do not consider the 12 per cent chrome iron studied a "welding grade" is because

it is a free cutting type containing sulphur. This fact we regret was not made evident in Table 1.

We have been aware for some years of a lower transformation range end on the WC4 type of steel. Therefore, we have been on the alert toward any practical evidence of untoward internal stresses and possible cracks. None have ever been found. It would seem that Mr. Kanter's hypotheses are hypotheses, inasmuch as his own charts show that the lower transformation range volume changes are quite small in relation to the gross or overall contractions that must be taken into account for all steels. Mr. Kanter is well aware of the lack of transformation in stable 18-8, yet we are sure that he would not contend that (as his argument would imply) 18-8 heated to molten condition and cooled therefrom is free from internal stresses. It is too well known that residual stresses in 18-8 are quite difficult to relieve.

Mr. Kanter's composition choices are unfortunate in that, while the WCB and WC1 steels are well within specification ranges, the WC4 is either somewhat above or at the top limits in each of the critical elements. There are definite reasons for the top established limits in WC4 and to exceed them minimizes the significance of the points Mr. Kanter seeks to show.

That CNM-25 or WC4 is sluggish in its transformation is quite true and it is partly on this property that it depends for its superior, long-time, elevated temperature properties. However, in our tests if the transformation were not complete, then residual martensitic or other hard decomposition products would be found. With preheating, no such structures were found and, if the preheating insured such complete breakdown, then certainly there was ample diffusion for relief of the transformation stresses.

Some years ago a number of tests were made on welds in various steels, examining the fusion joint by Charpy "V"-bar impact tests. (The inter-face was ascertained by light etching.) It is interesting to note that the WC4 type gave excellent impact values both with and without stress relief.

## Composite Molding in a Malleable Foundry

By S. W. HEALY\*, SAGINAW, MICH.

### Abstract

*With the beginning of automotive production, which entailed the use of castings in great quantities, foundries have progressed from loose patterns and hand-rammed gates of patterns to match plates and cope and drag machine equipments. These methods usually produce large quantities of identical castings from each equipment on a given run in the foundry. The purpose of this paper is to point out and illustrate the method used at the Saginaw Malleable Iron Foundry in deviating from the above procedure. The paper and photographs contained will demonstrate the grouping of patterns in composite equipments. The effect on scrap control, gating, foundry operations, and production control will be discussed. Composite molding has an added advantage of permitting a workman the opportunity of remaining on a given job for a longer period of time, which from an employee relation standpoint is very desirable.*

### INTRODUCTION

1. In the operation of a modern production foundry, castings are usually produced from match plate or cope and drag machine equipments.

2. These equipments are primarily designed to produce a large number of a given casting and generally consist of as many identical patterns per gate as flask size or production facilities permit. Fig. 1 is shown to demonstrate a differential carrier housing as formerly molded one-on. In this case, the weight of sand and flask is well under manual handling weight. Waste or unused space can be seen in this photograph.

---

\* Assistant to Works Manager, Saginaw Malleable Iron Division, General Motors Corp.

NOTE: This paper was presented at a Malleable Session at the 44th A.F.A. Convention, May 7, 1940, Chicago, Ill.

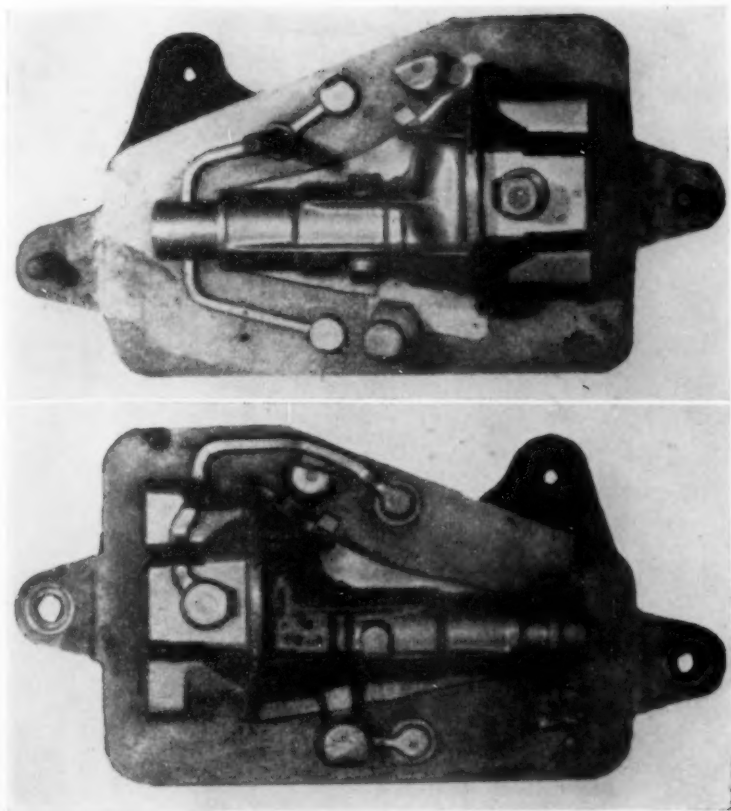


FIG. 1—DIFFERENTIAL CARRIER HOUSING AS FORMERLY MOLDED.

## COMPOSITE GROUPING

3. The molding of a variety of dissimilar castings in one mold is an old method of producing castings on the sample floor where most good molders ram up a small casting or two in their match when making a larger part. For several years, it has been customary, when production was a factor, to build equipments of only identical patterns in a given equipment. The problem of applying the combination-of-parts idea to production operations has made it necessary to discard the precedent of grouping identical castings and turn our thoughts to the grouping of various assemblies of parts. Fig. 2 demonstrates the carrier housing, shown in Fig. 1, combined to form an assembly with the differential case and, also, a spring hanger. All of these parts go on the same car.

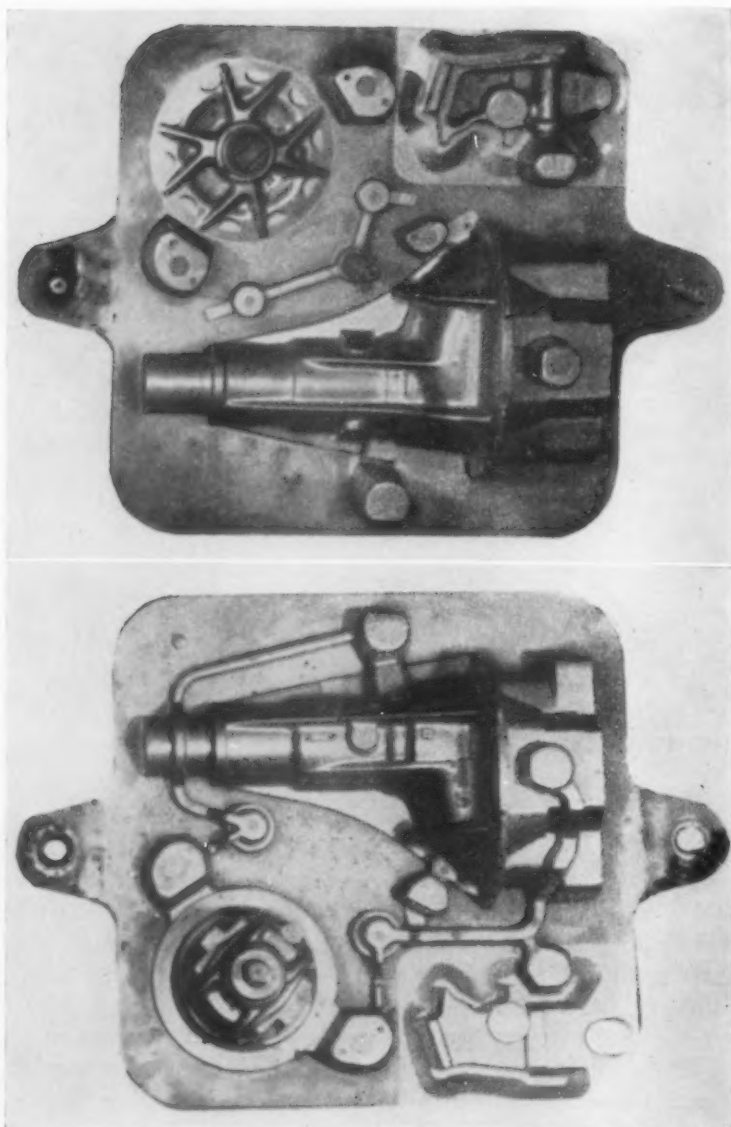


FIG. 2—DIFFERENTIAL CARRIER HOUSING OF FIG. 1 COMBINED WITH DIFFERENTIAL CASE AND SPRING HANGER.

## EQUIPMENT ENGINEERING

4. When engineering changes are made in castings, usually for the next year's models, prints are submitted of the new casting. These prints are used to make profile views of the part as it is intended to be molded, whether laying or standing up in the mold. The next step is to survey all new parts and all old parts that are expected to continue in production, and from this information, decide upon the various parts and combinations of parts that can be practically handled and fitted into standard flask sizes.

5. A number of factors must be considered which influence the grouping of the parts. Some of these are: Gaining fullest utilization of space in the mold, whether we can run another casting from some *particular* feeder, and whether the combination is in line with our practice of trying to maintain a reasonably uniform weight of metal to pour in each mold. Another very important factor to consider is the breaking up of combinations of parts which require an excessive number of subsidiary molding operations, such as the setting of cores or chills.

6. For example, in Fig. 2, the cores used in the carrier and case were set by a core setter working on the conveyor and the core used in the spring hanger was a ram-up core, which was set by the carry-out man working on the job. When the above factors are incorporated in foundry equipments, several operating advantages can be gained, such as, uniform daily tonnage, problems of excessive core setting eliminated, and the very important consideration of better scrap control. These advantages are to be mentioned in detail later on.

7. In many cases, certain parts going into a combination will not warrant as long a production run as other parts of a combination. In these instances, inserts are made which are interchangeable with other inserts and can be substituted as demand requires, in the pattern stool. Fig. 3 illustrates two interchangeable pattern inserts.

8. The question may be raised as to the value of composite molding to the small foundry. It would be entirely possible to use pattern inserts which could be made of wood or aluminum, thereby making cheap equipment for low production.

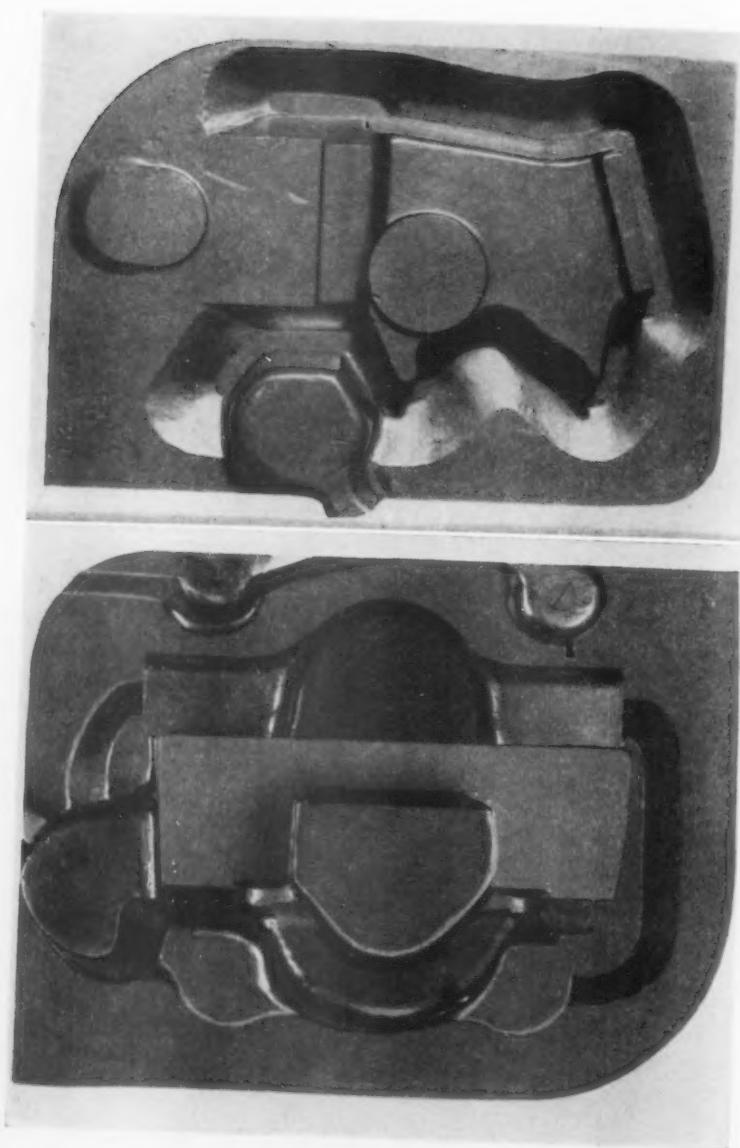


FIG. 3—INTERCHANGEABLE PATTERN INSERTS.

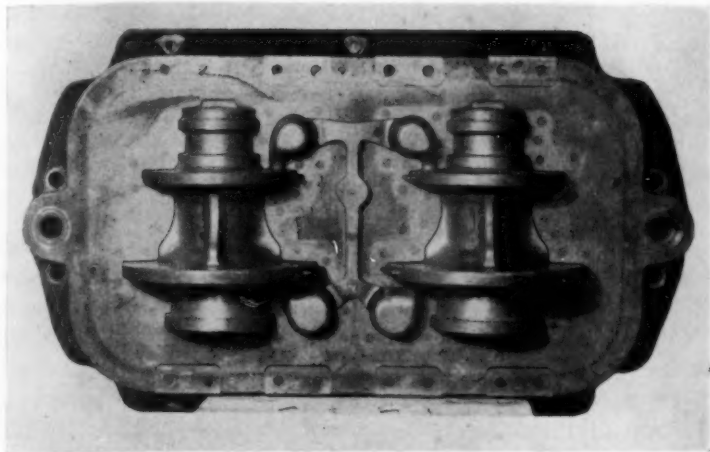


FIG. 4—DOUBLE-FLANGE HUB EQUIPMENT MOLDED TWO ON A PLATE.

*Effect on Yield and Pouring*

9. Pouring time per mold is a very important consideration in the continuous operation of molding conveyors. Instances have been found in which certain castings have been grouped with other

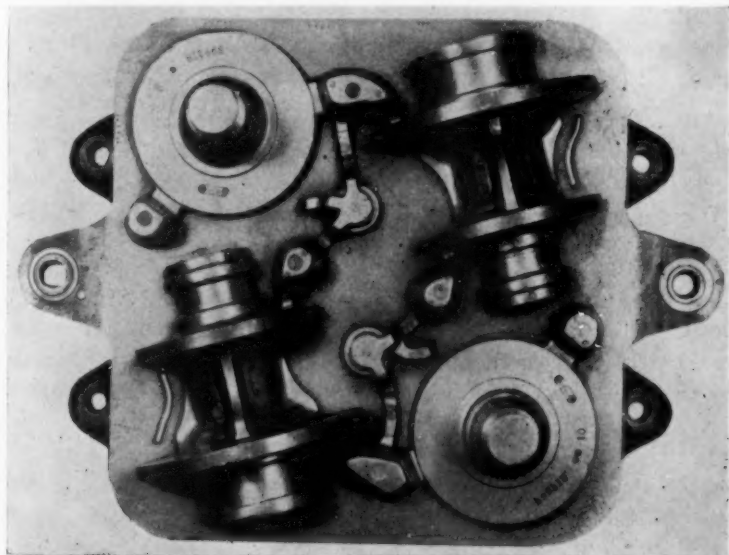


FIG. 5—SAME JOB AS FIG. 4 BUT PLACED IN COMBINATION WITH OTHER CASTINGS. POURING TIME FOR THE JOB AS CONSTITUTED IN FIG. 4 WAS 0.39 MIN. AND AS SHOWN IN THIS ILLUSTRATION 0.30 MIN.

castings and the total pouring time of the mold reduced. The pouring time could possibly have been reduced in the original mold. However, when it became necessary to change the gating, due to castings being added in the mold, these facts, which possibly otherwise would not have been discovered, were brought to our attention. Fig. 4 shows a double-flange hub equipment molded two-on.

10. In the production of these double-flange hub castings, it is necessary to use chills in the cores, and, to prevent scabs, the mold had to be poured quite slowly (0.39 min.) causing much difficulty in the pouring-off of the molds on the conveyor on which the job was running. Fig. 5 is the same job in which two front hubs have been placed in combination and can now be poured in (0.30 min.), due to the distribution of the iron in the mold in a manner causing less disturbance which permits the faster pouring

11. Fig. 6 demonstrates a steering gear assembly consisting of three housings, three flanges and three adjusting nuts, totaling 9 castings, which are poured from one sprue, due to the arrangement of the parts in relation to the sprue. The yield from this equipment is 55.8 per cent.

12. Fig. 7 shows the same housing as formerly made four-on which could not be poured successfully without the use of two sprues. The yield of the housing made in this way was 48.3 per cent.

13. Further advantage of placing patterns in a composite mold is pointed out in Fig. 8 in which we show a four-on hub which is so arranged on the stool that we are able to run four spring seats in combination which are fed from the hub feeders.

#### FOUNDRIY ADVANTAGES

14. Through the leveling off of peak tonnage points in the foundry, due to a well-balanced weight condition, it is not necessary to push the melting units at one time and run low at another time. Many operating problems have been solved; for example, core setting, which was very bad when some jobs running on the lines required as many as 18 cores per mold. By breaking down these jobs requiring excessive cores and running them with proper combinations of jobs requiring few cores, the trouble has been minimized. It is obviously a more simple matter to control scrap when a pattern is run for a considerable length of time.

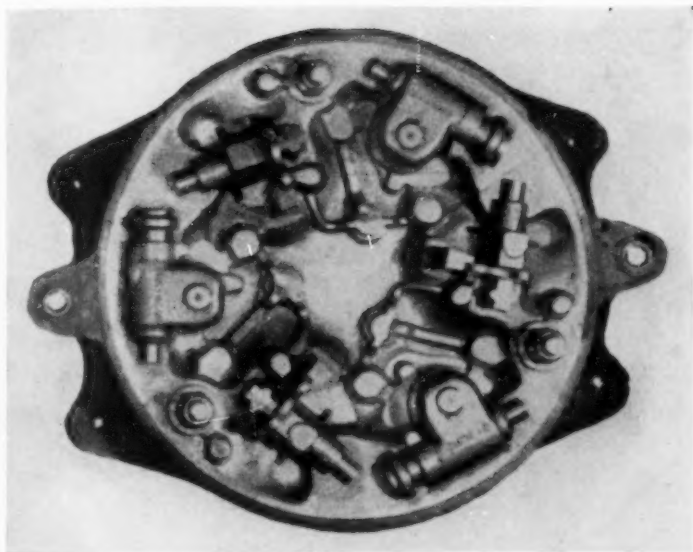


FIG. 6—STEERING GEAR ASSEMBLY CONSISTING OF THREE HOUSINGS, THREE FLANGES AND THREE ADJUSTING NUTS, TOTALING NINE CASTINGS. YIELD FROM THIS COMPOSITE EQUIPMENT WAS 55.8 PER CENT.

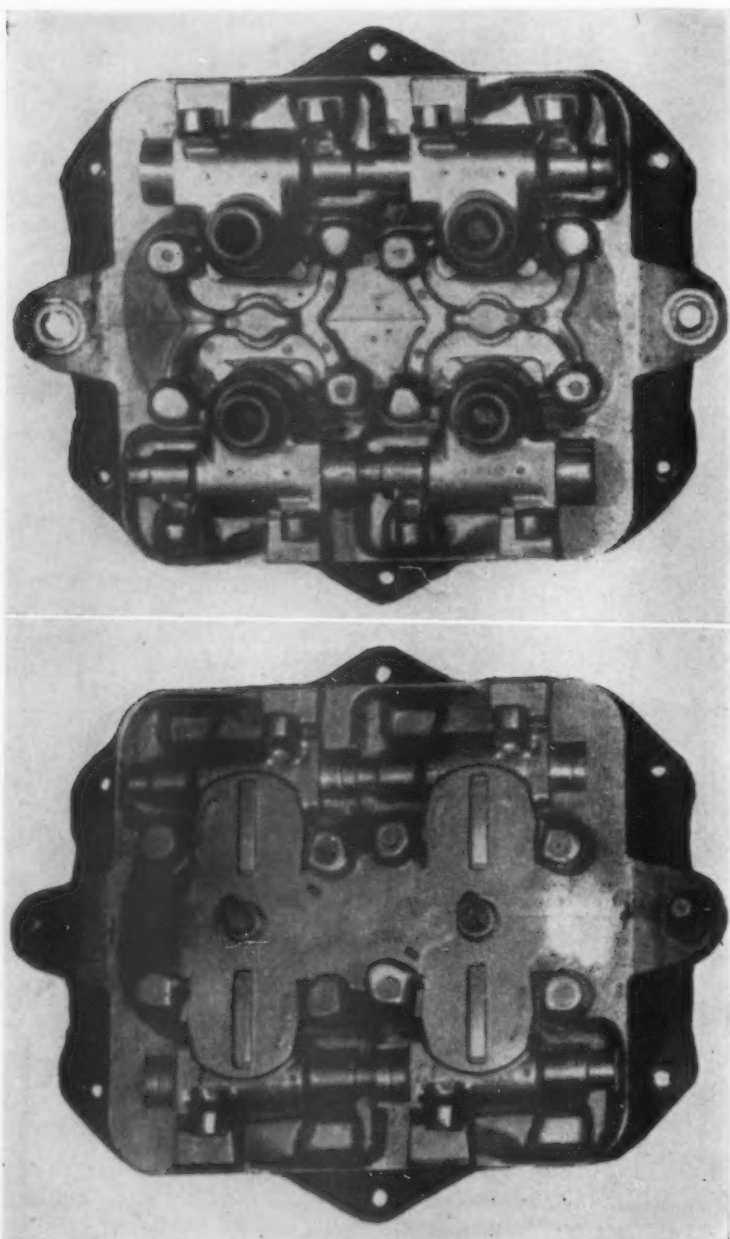


FIG. 7—HOW SAME HOUSING, AS SHOWN IN FIG. 6, WAS FORMERLY POURED. TWO SPRUES WERE NECESSARY. YIELD WAS 48.3 PER CENT.

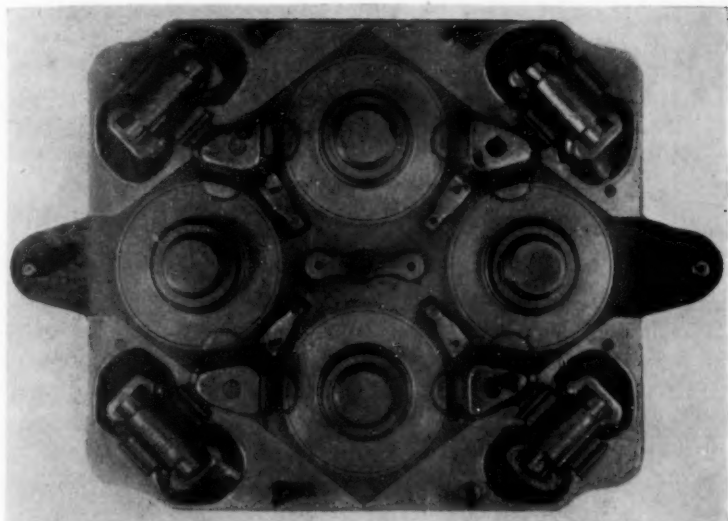


FIG. 8—PLATE WITH FOUR HUBS ARRANGED SO AS TO POUR FOUR SPRING SEATS AT THE SAME TIME. SPRING SEAT CASTINGS ARE FED FROM THE HUB FEEDERS.

### *Pattern Changes*

15. Pattern changes are brought to a minimum through the use of this type of molding. In operating a malleable foundry, due to the wide variety of parts produced, the length of run on a given pattern equipment is quite naturally short due to the necessity of changing jobs often enough to get the required turn-over per molding station to produce the variety of parts necessary. The number of pattern changes a foundry can eliminate has a marked effect on cost. There is, of course, the cost involved in the actual change of patterns and resultant scrap. But more important is the dissatisfaction of the workmen, not only in the foundry but all through the plant, when their work is being changed constantly.

### *Flask Equipment*

16. Two types of flasks are used in our foundry: (1) a cast steel flask which is somewhat heavy and is used on jobs where weight is not a governing factor, and (2) a fabricated steel flask of light construction which is used where weight is a factor. With the light steel flask, we are able, in many cases, to reduce the total mold weight from 20 to 25 lb.

17. Flasks used in composite molding are standardized into three sizes 20 x 23-in., 20 x 20-in., and 24-in. circular. The depth of the flask varies as the castings permit.

18. The use of standard-size flasks simplifies job changes and, in many cases, patterns can be changed and the same flask used, which eliminates the necessity of much flask changing.

#### *Molding Equipment*

19. The majority of our molds are made on 16-in., jolt-squeeze-stripping machines. The machines are equipped with automatic timing devices which are set for the number of jolts required for various castings. After these timers are set, each mold is made with a uniform number of jolts. We are also equipped with automatic squeeze controls which insure each mold being squeezed at full line pressure. The control of jolt and squeeze conditions is a definite factor in maintaining closer casting dimensions and limiting scrap losses.

#### *Production Control*

20. Many of the difficulties of production control and planning of work through the shop, are simplified through the use of

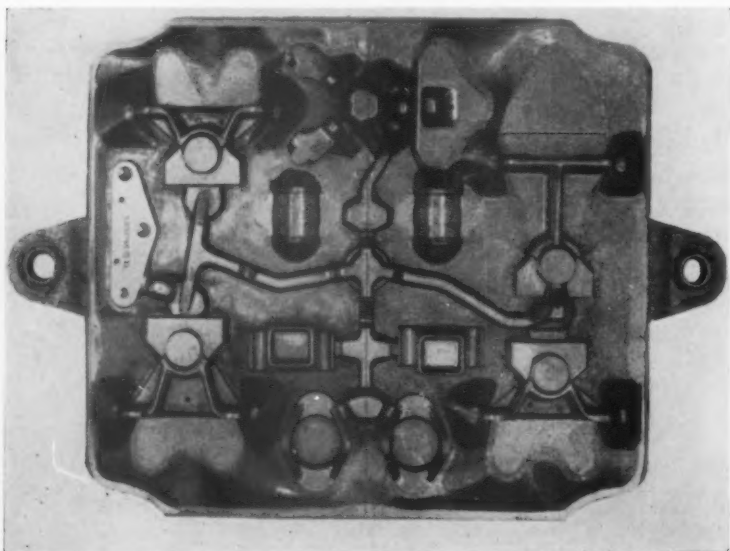


FIG. 9—A GROUP OF TEN DIFFERENT CASTINGS, CONSISTING OF 14 UNITS, MADE IN ONE MOLD. THESE CASTINGS PAIR UP TO FORM SETS.

composite molding. It has always been a problem when large quantities of certain groups of castings would go through our production process. Some groups throw an unusual burden into the core department, others into the hard iron and annealing departments and so on through.

21. For example, referring back to Fig. 1, it would not have been unusual for us to run five of the one-on carriers pictured. It would then, possibly, have been necessary to take out one of the carriers and run a four-on differential case long enough to balance up the jobs, inasmuch as they are used together. Another production period would, possibly, cause us to run only one of the carriers to make available molding stations for other work. We now find it possible to run three of the equipments shown in Fig. 2 steadily throughout the model at practically all times. This means a relatively steady employment on a certain job for the employees involved.

22. Fig. 9 shows a group of ten different castings, and a total of 14 units in one mold which pair up to form sets used by one customer. This mold produces over one-third of the castings made for this user.

#### CONCLUSION

23. The unit pictured in Fig. 9 suggests making a mold containing all parts used in the various assemblies of individual customers for which we might produce. A mold of this size would present many problems but it is possible. Our development in size of equipments has been limited in scope to the size molds that can be handled manually. It is being learned constantly that many pre-conceived ideas in gating which are called good practice, are not necessarily facts in all cases. A distinct advantage has been found in material handling through the continuity gained by annealing and processing in closer ratio to the assembly of parts as used by our customers.

## DISCUSSION

*Presiding:* C. C. LAWSON, Wagner Malleable Iron Co., Decatur, Ill.

MEMBER: Does the author ever find that production is thrown out of balance by heavy scrap loss on one run and have the other run good? If that is the case, you end up way ahead on one run and behind on the other.

MR. HEALY: We do. However, it is a very simple matter to control. As I said before, we use inserts primarily to pick up quantities on which we might be short for certain particular parts to match up with quantities that we need on longer run parts. Most of these jobs are mounted patterns and can be changed. The jobs that are not mounted jobs are usually made in insert form and can be changed, and in that way we can control the production. Ordinarily, the difference encountered in the balancing up of parts is on the smaller castings, which, due to loss or breakage, throws them out of balance with the heavier jobs. On most of our smaller jobs, we make up a hand plate that we run in the foundry to pick up an unusual condition. That is a very good point but it is simple to control.

MEMBER: The author mentioned something about either cutting down or increasing a gate to reduce cuts.

MR. HEALY: I was not speaking of reducing cuts. I was speaking about a condition we had on a certain job in which we had a mottled condition. The only control we had over that condition was the use of chills in the cores. The point that I was making was that our metal was flowing over those points, surged in, causing a disturbance, which is conducive to scabs. In this particular instance, the way to avoid the scabs was to slow up the iron. My point was that in the other equipment, due to a different arrangement of gating and to a different means of getting the metal into the mold, we eliminated the disturbance and, therefore, could open our chokes and pour the jobs faster by 30 per cent.

MEMBER: How large were the openings in those skim cores? What capacity would you have?

MR. HEALY: There is always some question about the capacity of a skim core. Many people maintain that such cores will take a certain amount of iron due to the size or the area of the openings. However, I believe this is a fallacy. I know that I can pour a mold either 30 or 40 per cent faster, depending on where the skim core is or where the choke is. In this particular case, we put a skim core in the cope, which really does retard the flow of the iron. Getting the skim core down to the parting, of course, does not retard the iron as much as it does when in the cope. The job that you are referring to was poured with the skim core in the cope. After the gating was changed, we put the skim core at the parting, which is really the reason for the increase in pouring speed.

MEMBER: Which do you find is the best to reduce your slag, a skim core in the cope or in the parting?

MR. HEALY: I think on a job that is very "slaggy," you will take more slag out by putting the skim core in the cope. I do not believe that anyone will dispute that. However, probably you can accomplish more by re-gating it.

MEMBER: What is your approximate increase of salable castings by this method as compared with your previous method?

MR. HEALY: I would say about 2 or 2.5 per cent.

MEMBER: You mentioned one yield of 48 per cent and another of 65 per cent.

MR. HEALY: That sounds good, but do not forget there are also some good jobs that are lower. Some jobs, running by themselves, would probably have a yield of 60 per cent but when you put them in the composite, the total yield might be down to 55 per cent.

MEMBER: If you had an average 2.5 per cent increase in yield over 800 tons a day, that is a good saving.

J. H. LANSING:<sup>1</sup> In your illustrations, it was interesting to note that the hub was gated into the flange and yet presumably fed so as to be satisfactorily sound. Another point was that the runners used on the different patterns appeared to vary considerably in size. I was wondering if you had any particular purpose in using a narrow runner on the carrier. The runner did not look as large as those on some of the other parts that were shown. That might have been misleading from the size of the picture, but that was the general impression I got.

MR. HEALY: The reason that the runners looked to be larger on the hub is the fact that we found a slag condition there has been helped by flattening out that runner and pinching down the rate of pour. However, there is plenty of area to supply the metal. We do not feel that it has any particular effect on shrinkage, except it probably does have a chilling effect at the gate. The prime reason for flattening out the runner is to retard slag.

You questioned our producing the hub casting with the gate on the flange. The flange of that hub is fairly heavy and we can feed out through it. We do make some, however, that have thin flanges and we have to go in with a gate there, like everyone else.

J. H. LANSING: You spoke of having a little trouble with primary graphite on one job. As I understand it, you are using the chill in the core to reduce it. Was there any other expedient that you found effective in reducing the tendency to graphitize?

<sup>1</sup> Shop Practice Engineer, Malleable Founders' Society, Cleveland, O.

MR. HEALY: No. There is quite a narrow and deep pocket that stays very hot and that was the only thing that we ever found that would remedy the condition. We have changed it since, by putting a chill into the round cup core that goes next to the flange and throwing the chill up that way, but it is still a chilling method.

MEMBER: With this method of molding, using so many in the mold, having the feeds working on the two castings and having the heat all concentrated at one spot, do you run into many cracks right in the mold?

MR. HEALY: No.

MEMBER: I noticed on some of the hubs you had cracking strips into the flange.

MR. HEALY: That is right, and we had them before we combined them. Probably the only reason that they ever cracked was due to the range of sections in a certain area, one chilling, of course, and one remaining hot. However, I do not believe that the heat of the feeder that far from the casting, whether or not there would be a gate off from the other side of it, would affect it enough to cause a condition that would be any more severe than the condition that we had had before. The bob probably is no larger and, if any larger at all, it probably would not be over 1 per cent larger. Merely the fact that it would be feeding another casting from the opposite side, I do not believe would have any effect on the casting. At least, we have not found it to be so.

MEMBER: Possibly you have had a type of casting which required a special form of molding, which would not group with other castings that you had to make. Have you ever had a complete failure like that?

MR. HEALY: No, we have not. For instance, we get prints of the casting that we intend to make, or that the customer intends to have us make, the early part of the year and we attempt immediately, if we run into any conditions that are not conducive to our set-up, to get concessions. It is a relatively simple thing to do if a person can get on top of it long enough before a model starts. In case after case, we get concessions to make a job more desirable to fit into a set-up or to run the way we would like to run it. To date, we have not had a job that has been a complete failure in composite.

## Cooling and Storage of Foundry Sand

By H. L. McKINNON\*, CLEVELAND, OHIO

### Abstract

*Two of the most important problems that confront the production foundry are the cooling of its molding sand and the storage of the same conditioned sand. In the first part of the paper, the author discusses sand cooling problems and cites examples of how the application of the proper equipment, together with correct control, has solved this difficulty in several shops. The second section of the paper is devoted to the proper design and installation of storage bins and hoppers.*

### Part I—The Cooling of Foundry Sand

1. One of the problems growing out of continuous foundry operations is that of bringing the sand back to a desirable temperature for molding. The reasons for this appear to be as follows:

- (1). Moisture cannot remain constant when sand is hot.
- (2). Uniform strength is not possible at high temperatures.
- (3). Hot sand is likely to cause sweating on the patterns.
- (4). If sand is properly cooled, there is less chance for drops in copes.

#### SOME EXAMPLES OF SPECIFIC FOUNDRY CONDITIONS

2. In the older types of foundries, sand was never used more than once a day, and radiation usually gave ample cooling during the 24 hr. period. Today, with many types of foundries, the problem has changed completely. A few examples will suffice to outline the general problem.

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\* Vice President, The C. O. Bartlett & Snow Co.

NOTE: This paper was presented at a Plant Equipment Session of the 44th A.F.A. Convention, May 6, 1940, Chicago, Ill.

(1). A modern car wheel foundry frequently pours more weight of metal into a mold than the total weight of the sand. These molds, being shaken out in about 20 min. after pouring, give an average temperature in sand at shakeout of upward of 900°F. At such temperature, it is evident that the sand cannot be used in from 1 to 2 hr. without treatment. In other cases, the ratio of sand to metal is approximately  $1\frac{3}{4}$  to 1, producing a temperature of 600°F.

(2). Furnace and boiler foundries, in many instances, work with a range of sand to metal below 4 to 1, which produces a cooling problem.

(3). Many steel foundries are pouring a high ratio of metal to sand in both green and dry sand molds, and creating a temperature too high for re-use without adequate preparation.

(4). Sand-spun pipe is another product which, due to amount of metal poured per pound of sand, creates a high temperature. This class of work can re-use the sand at temperatures approaching 200°F., since the time interval between molding and pouring is brief.

#### SOME RESULTS OF STUDY OF COOLING

3. After observing the hot sand problem in these foundries and many others, it was decided that a definite study should be made which would serve as a guide to our engineers in their studies of foundry problems. Experience showed that the customer usually did not consider this problem when increasing production. A large number of installations have been analyzed and the set of curves, submitted herewith, has been prepared as a means of predicting the temperature when any given set of conditions is fully known.

##### *Curves Based on Assumed Conditions*

4. Fig. 1 shows a temperature curve for various ratios from approximately 1 to 1, to 10 to 1 of sand to metal; that is, if 1 lb. of sand is used for 1 lb. of metal, the temperature approaches 900°F. The assumptions set forth in Fig. 1 are as follows:

Temperature of Foundry Air..... 70°F.  
Pouring Temperature of Metal..... 2700°F.

Further, that one-half of the moisture content in the molding sand in a green sand mold is evaporated and that radiation

through flasks and material is equal to approximately 20 per cent of the total heat in the metal.

5. The average specific heat of the metal during the cooling period has been assumed at 0.17 which is a little high. The specific heat of the sand is taken at 0.24. These charts are based on initial moisture in the molding sand of 3 per cent. Temperature of the sand is plotted in Fig. 1 on the assumption that the metal has

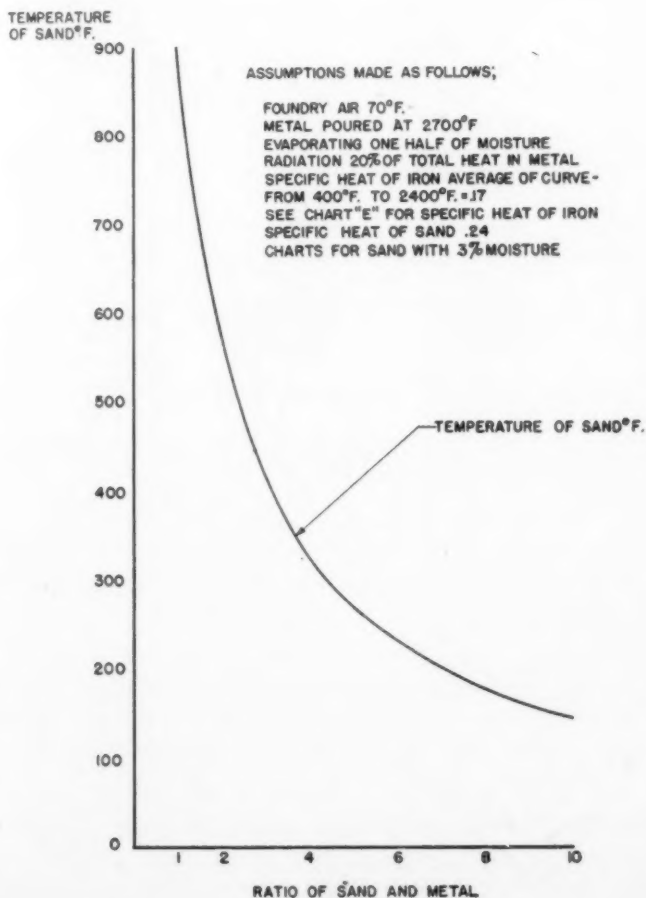


FIG. 1—CHART "A" SHOWING TEMPERATURE OF THE SAND AT THE SHAKEOUT WITH VARIOUS SAND TO METAL RATIOS, ASSUMING THE CONDITIONS OUTLINED IN PARAGRAPH 4.

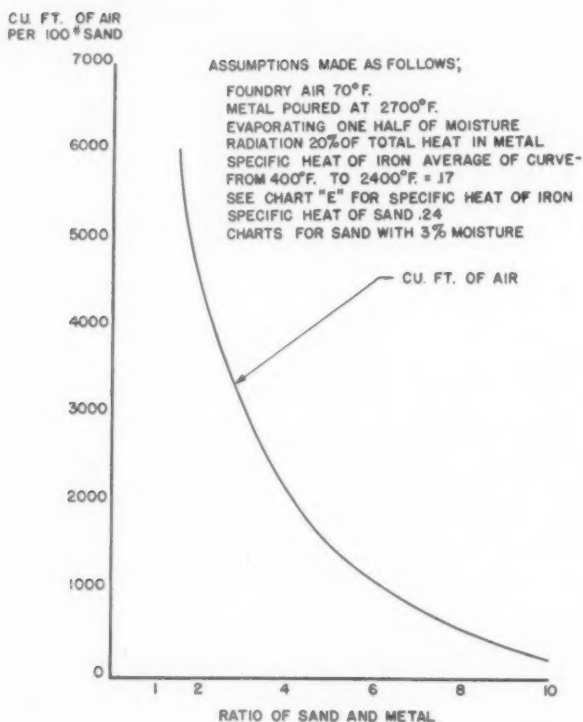


FIG. 2.—CHART "B" SHOWS THE CALCULATED AMOUNT OF AIR IN CU. FT., REQUIRED TO COOL 100 LB. OF SAND WITH VARIOUS SAND TO METAL RATIOS, ASSUMING THE CONDITIONS GIVEN IN PARAGRAPH 4.

been in the mold for at least 15 min. after pouring and before the casting is shaken out.

6. Fig. 2 shows the calculated amount of air which it is necessary to circulate through the sand for cooling purposes; that is, the curve is set up for the cubic feet of air required per 100 lb. of sand—all based on the ratio of sand to metal running from approximately  $1\frac{1}{2}$  to 1, to 10 to 1.

7. Fig. 3 is a similar chart, which indicates the amount of water required to be added in conjunction with the air, to reduce the sand to a reasonable temperature.

8. Fig. 4, a combination of Figs. 1, 2 and 3, with different scales, shows the relationship of air and water to the temperature of the sand.

9. Fig. 5 is plotted from data\* and shows specific heats of the iron at various temperatures from 100 to 1300°C.

#### Checking Curves with Operating Conditions

10. It is very difficult to set forth in curves all of the conditions that are likely to obtain in any given foundry, because of the great variety of work, especially where jobbing work is done. However, the author has had occasion to check his tables in a number of installations, and has found the curves to check rather closely as to actual temperatures.

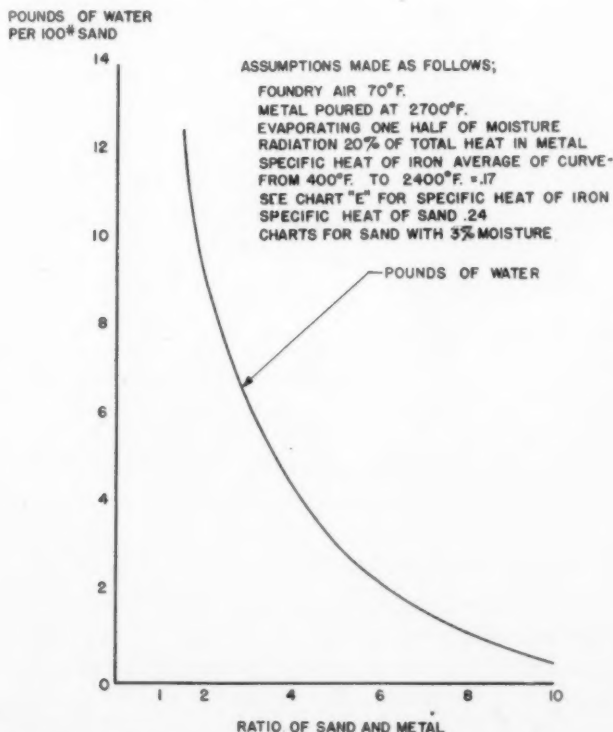


FIG. 3—CHART "C" INDICATES THE AMOUNT OF WATER THAT MUST BE ADDED IN CONJUNCTION WITH THE AIR TO REDUCE THE SAND TO A REASONABLE TEMPERATURE, ASSUMING THE CONDITIONS OUTLINED IN PARAGRAPH 4.

\* *Cast Metals Handbook*, American Foundrymen's Association, 1940 Edition, Table 163, D. 445.

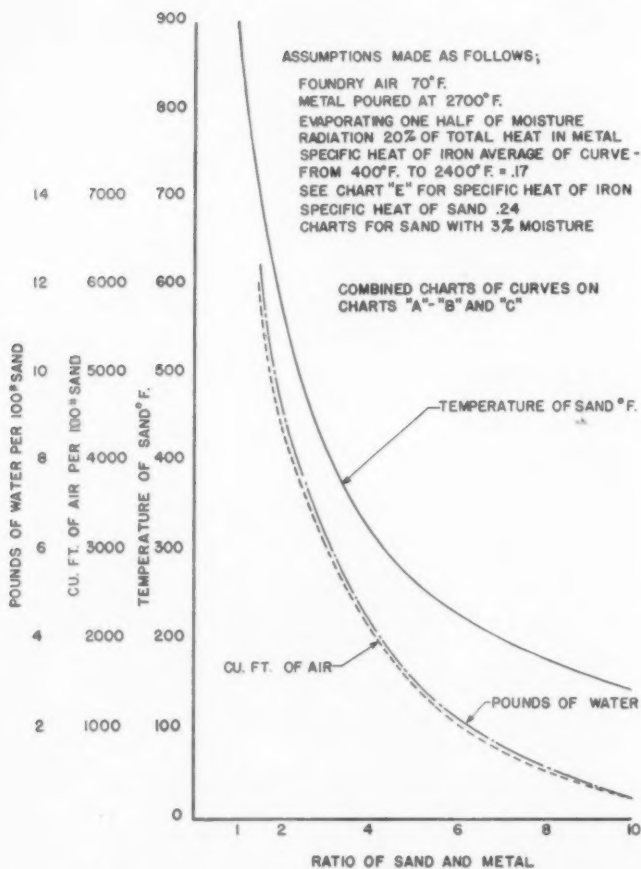


FIG. 4—CHART "D" IS A COMBINATION OF FIGS. 1, 2 AND 3, USING DIFFERENT SCALES, AND SHOWS THE RELATIONSHIP OF AIR AND WATER TO THE TEMPERATURE OF THE SAND.

11. A few instances will suffice:

(a). In a mold for light work, where the ratio of sand to metal was approximately  $8\frac{1}{4}$  to 1 by actual test, after 14 min. in the mold, the average temperature was found to be 156°F., where our scale would have indicated 162°F.

(b). In another case, where the ratio of sand to metal on a production job was 3.75 to 1, the temperature shown on our chart is figured at 365°F. The observed temperature—the metal being in the mold for 50 min.—was 420°F.

(c). In another case, where the ratio of metal to sand was 1.8 to 1, the observed temperature was  $620^{\circ}\text{F}$ ., where our curve would make it  $660^{\circ}\text{F}$ .

These differences are due, first to the long period between pouring and shakeout, and second, to the variation in moisture content from the assumed moisture content on which the calculations are based.

#### METHODS FOR COOLING

12. As to the means which may be employed for cooling sand, it is evident that a great variety of methods could be used. If the sand can be passed through the air in a sufficiently thin stream, it will approach the air temperature rather rapidly at first. However, as the "temperature head" becomes less, the rate of interchange of heat will slow perceptibly; and, while it is theoretically possible to bring the sand to the air temperature, this could only take place if sufficient time, and ample facilities for separating the sand, were available.

13. Another method, which has been used, is to produce a sudden drop in high temperature sand by the addition of water.

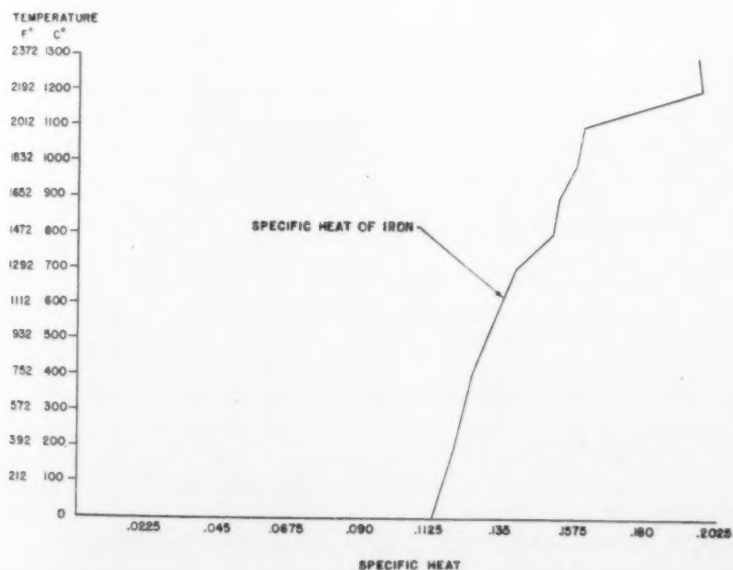


FIG. 5—SPECIFIC HEAT OF IRON AT VARIOUS TEMPERATURES FROM 100 TO 1300°C.

The water is mixed with the sand and, as the steam is driven off, the sand will lose heat equivalent to the evaporation of the moisture.

14. Many other methods might be used for absorbing the heat in the sand to drop the temperature to a workable range. In one instance, the author's company has used a spray of water on the outside of a rotating shell. The water was constantly recirculated so as to keep the outside of the shell at reasonably low temperatures, and in this manner absorbing the heat from the sand on the inside of the rotating drum.

#### *A Practical Method*

15. However, in general, the simplest practical method of cooling sand from above 200°F. is by the addition of the correct amount of water together with agitation in a rapidly circulating atmosphere. This is most easily accomplished when the correct amount of water is added while the material is traveling on a conveyor which is hooded and exhausted. The control for this water should be through an averaging thermometer actuating a motor-operated water valve. If the correct amount of water is added, the cooling is obtained without allowing excess moisture to remain in the sand.

16. In one case, where the average temperature of the sand at the shakeout was approximately 400 to 420°F., by the addition of 6 lb. of water to 280 lb. of sand, the temperature of the sand was reduced to 175°F. in a few seconds. Further, that by sending the sand successively through a bucket elevator, a revolving screen and an aerator, the sand temperature was reduced to approximately 125°F. in the storage bin.

17. To obtain such a result, air was circulated as follows:

(1). From the elevator, 1000 cu. ft. per min.

(2). From the aerator and screen, a total of 6000 cu. ft. per min.

18. The sand was handled at the rate of 36 tons per hour.

#### *Cooling from 700°F.*

19. In another installation, the sand was received from shake-out hopper at approximately 700°F. and fed onto an apron conveyor 24-in. wide and 60-ft. long, hooded throughout the entire length. The conveyor delivered the sand to a revolving screen which also

was hooded. A mechanically controlled water valve was arranged so that the amount of water delivered was proportioned to the volume of sand on the conveyor. The conveyor and screen were exhausted with a fan handling about 15,000 cu. ft. of air per min.

20. The speed of the conveyor was variable from 8 to 30 ft. per min., but, with valve adjusted, it operated at a fixed speed. The temperature of the sand was reduced about 450 to 500° in passage through these units, giving a final temperature a little above 200°F., which was desired by the customer. Such an arrangement can only be employed when the sand is coming from shakeout in nearly uniform molds.

21. A rotating cylinder with lifting flights, arranged to cascade the sand through the atmosphere in the cylinder, and the addition of water through a control valve, actuated by a thermometer placed in the path of the outlet air, also has been used. A patent has been recently granted to the author's company for such an apparatus.

#### *Ample Circulation of Air Necessary*

22. All such devices depend upon an ample supply of circulated air and it should be borne in mind that it is not possible to drop the temperature of sand below that of the air supply. In fact, a margin of 15 to 20°F. should be allowed.

23. One such installation consisted of a revolving shell, 42-in. in diameter, 14-ft. long, arranged to self-feed from the shakeout at the rate of 5 tons of hot sand per hour. Approximate temperatures ranged from 900 to 1200°F. at inlet, and the sand was cooled to 200 to 230°F. at the discharge. Sand was then fed onto a rubber belt without injury to the belt.

#### *Relation of Air to Water*

24. It is very important that the amount of air handled shall have a direct relation to the amount of water added, when it is desired to get efficient cooling of the sand. We have found that if sand can be cooled, before storage, to approximately 125°F., it may then be mulled, aerated and ordinarily delivered to the molders at temperatures between 90 and 100°F., which for most practical purposes appears to be satisfactory. Some difficulty might be found in obtaining as low a temperature as this in extremely hot weather, but there are only a few days in the year when the

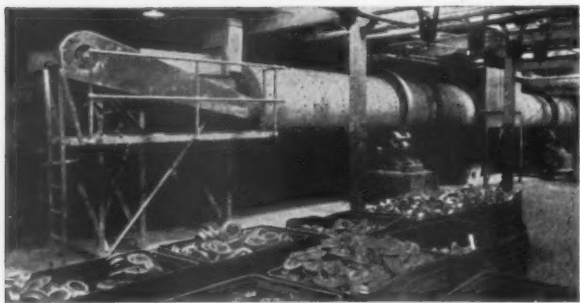


FIG. 6—ROTARY COOLER INSTALLATION SHOWING THE SHELL AND RIDING RINGS.

temperature of the ambient air would be such as appear to make it impractical to reduce the sand temperature to  $100^{\circ}\text{F}$ .

25. The importance of the proper temperature control can readily be seen when it is considered that, if sand is put into the mold with the proper amount of moisture for ordinary strength, and if the temperature is appreciably above  $100^{\circ}\text{F}$ ., there is a distinct tendency to dry out the face of the mold rather rapidly. If the temperature is below  $100^{\circ}\text{F}$ ., such a condition does not normally cause any difficulty.

#### COOLING CASTINGS

26. During the past 10 or 12 years, in various places, the author's company has been called upon to cool castings, as well as the core sand contained in them, in a continuous unit.

27. The equipment used in this connection is illustrated in Figs. 6 and 7. These are cylindrical shells lined with high carbon

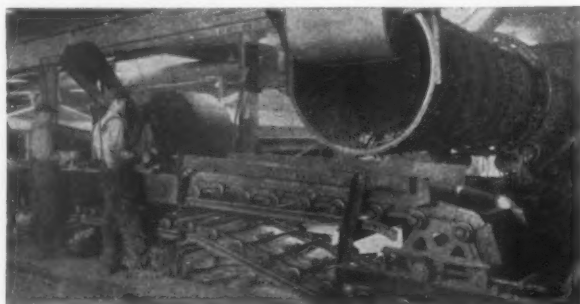


FIG. 7—CASTINGS BEING DELIVERED FROM A ROTARY COOLER TO AN APRON CONVEYOR.

steel wearing plates, and sometimes furnished with triangular flights about  $\frac{3}{4}$ -in. high. These flights are arranged to turn the castings over from time to time, and prevent wearing flat spots on the castings when passing through the machines. If the castings are round rather than flat, no flights appear to be necessary, but where flat castings predominate, some form of interrupter is very desirable.

28. As will be noted in Fig. 6, about midway of the length of the unit, there is an outer housing. Underneath this housing, the shell and its liners are perforated with holes to permit the removal of air drawn into the cylinder. This also serves as an easy place to separate the sand from the castings. The sand is practically all freed from the casting after one-half of the travel needed for cooling the casting.

29. Fig. 8 shows an actual test made on one of these machines when it was handling approximately 18 tons of castings per hour, the average weight of such castings being about 2 lb., representing a wide pattern variety. The unit is in a foundry doing jobbing and contract work.

## Part II—Sand Storage

30. The Committee requested the writer to submit his ideas on sand storage bins as a part of this paper.

31. The author is assuming that steel is the material to be used in making the bins. There are a number of places where wood or concrete have been used, but, in general, if sand must be stored, a foundryman expects that it will be in a steel bin.

32. In our judgment, there are three distinct questions to be considered in this connection. Accordingly, this discussion is divided as follows:

1. Storage of shakeout sand or dry sand.
2. Tempered sand storage.
3. Storage of tempered sand in molders' hoppers.

Each of the above represents a separate problem.

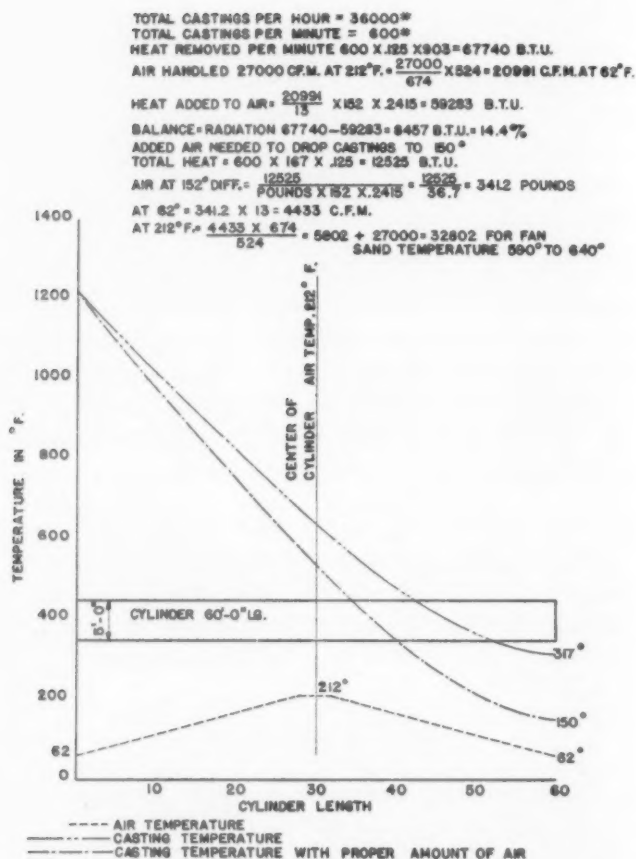


FIG. 8—CHART SHOWING DATA OBTAINED ON A ROTARY COOLER HANDLING APPROXIMATELY 18-TONS OF CASTINGS PER HOUR. THE AVERAGE WEIGHT OF THE CASTINGS WAS ABOUT 2 LB., REPRESENTING A WIDE PATTERN VARIETY.

### STORAGE OF SHAKEOUT SAND

33. In approaching the foundry sand-handling problem, for many years the author's company has consistently recommended that the main storage bin, for any sand system, should be capable of holding at least a 2-hr. supply of tempered molding sand. The reason for this is the fact that sand will season after the moisture has been added; if it remains in a compact pile for at least a 2-hr. period, it will improve in condition, due to better distribution of the moisture over the smaller particles of sand in the system.

34. The variation in requirements of molding sand in foundries is very wide. We have, within the past few weeks, found shops working with a moisture content as low as 1.3 per cent and using a comparatively fine grain sand; while other foundries have been found operating with a moisture content up to as high as 8 per cent, with sand not much finer than that mentioned with the lower content. A great many plants are now operating under 3 per cent moisture.

35. However, the average grain size of the various grades of sand does have quite an influence on the amount of moisture necessary to get similar working conditions. Perfectly dry, pure silica sand will flow on an angle of approximately  $35^{\circ}$ , whereas silica sand mixed with from 15 to 30 per cent fine clay, even though dry, would tend to arch and not slide, even on an angle of  $45$  to  $50^{\circ}$ .

35a. The storage of dry sand does not present many serious obstacles. In general, the amount of clay mixed with molding sand will determine the flow angle of the material. On account of the variable nature of sands, and of molding sands in particular, conservative practice in respect to such bins is recommended.

#### TEMPERED SAND STORAGE

36. The addition of moisture increases the problem of handling sand to such an extent that we have made it a rule to set the minimum angle for tempered sand bins at  $60^{\circ}$  with the horizontal; and we have tried, as far as possible, to limit the hopping to two surfaces, with a minimum angle of  $60^{\circ}$  to the horizontal. This applies, of course, to tempered sand, such as is used in gray iron or malleable molding.

37. It also has been found desirable to have the inside of the hoppers perfectly smooth, using countersunk rivets or welding.

38. The minimum size of openings in the bottom of bins is of much importance. In bins of over 50-tons capacity, we do not try to remove tempered molding sand with an opening less than 18-in. wide. For the purpose of getting removal of sand over the entire area of the bin simultaneously, a patented type of feeder has been designed which has worked very satisfactorily on damp molding sand. This is illustrated in Fig. 9.

39. As will be noted from the illustration, the feeder consists of a series of parallel, horizontal, bars with one end of each sup-

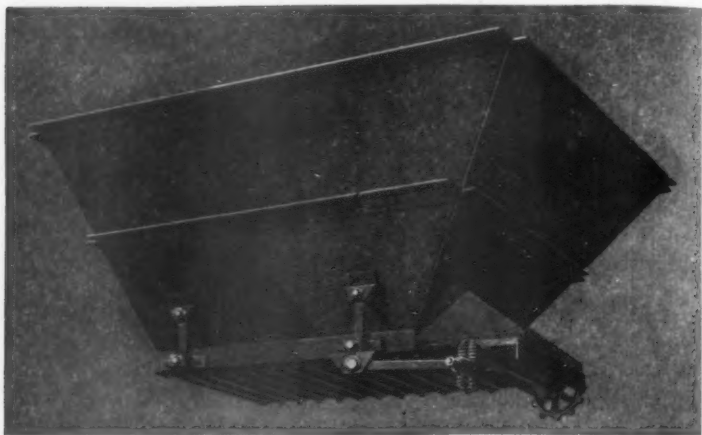


FIG. 9—SEASONING BIN WITH CUTTING FEEDER. NOTE MOUNTING STIRRUPS AND CRANK.

ported from the bottom of the hopper itself, while the opposite end is carried on a reciprocating member, in turn supported on stirrups. These stirrups force a sort of compound motion which has the effect of breaking the arch that tends to form in the hopper. As the reciprocating member approaches the end of the travel, the stirrups carry to the highest point; and as it swings back to the center, it is in a lower position. This compound motion has the effect of getting very good distribution from the bottom of a hopper and drawing sand from the entire area of the hopper simultaneously.

40. Other methods have been used for removal of sand from hoppers, particularly the use of apron feeders. The general effect of an apron feeder is to draw sand from the farthest point in the bin, which produces a very bad condition if return sand is being put into the bin at the same time prepared sand is being drawn from the bin. This results in merely a recirculation of the return sand, as it will flow to the lowest opening in the bin and will be drawn from the back end of the bin continuously. However, some improvement has been accomplished by placing a series of diaphragms at varying heights above the conveyor.

41. A number of engineers have felt that the proper way to remove sand from large storage bins was by the use of gates and weigh or measuring hoppers, either stationary or mounted on larry trucks. Such an arrangement does not permit drawing from the entire length of the bin, but if a large number of gates is used, this desirable result may be approximated.

42. One of the objections to this type of bin is the increased head room required, and in most handling installations, "head room" is one of the things hardest to obtain. The engineer is either required to keep under an existing roof or, as frequently occurs, he is asked to keep under a traveling crane or some other obstruction.

#### *Storage Bins*

43. Storage bins for tempered molding sand, even if they are limited to two sloping surfaces, have a tendency to accumulate sand on the side plates in the form of a half oval, extending from the outlet at the bottom to a point slightly above the point where the sloping surface meets the vertical surface of the upper part of the bin.

44. If the bins could be emptied every day, this might not cause much difficulty. If, however, as is frequently the case, the sand lies dormant from Thursday or Friday to the following Monday or Tuesday, it seems to cement itself on the sloping sides and reduces the active capacity of the bin.

45. It is recommended that men be sent into these bins as frequently as twice a month, using bars to loosen this caked sand from the plates. The author knows of no way to prevent some accumulation, but the use of lacquer, glass or stainless steel liners, does promise some relief.

46. From an operating viewpoint, the one mistake most frequently made in the design of sand handling systems, is cutting down on the amount of storage; and after nearly 30 years of effort in persuading foundry managers to provide ample storage capacity, we are still frequently told that the owner cannot justify the additional expense.

47. Further, it is rare indeed that returned shakeout sand in a foundry is commercially dry, and so we must be prepared to handle it with a variable amount of moisture. Therefore, design should follow the practice of tempered sand.

#### STORAGE OF SAND IN MOLDERS' HOPPERS

48. With regard to the design of molders' hoppers, these again must be constructed with due reference to the size of molds



FIG. 10—MOLDERS' TOPPERS AND HOPPER GATES, SHOWING AN ARRANGEMENT THAT FEEDS SAND TO TWO MOLDING LINES FROM A SINGLE DISTRIBUTING SYSTEM.

which are to be served; and they must be arranged so that the flasks may be readily put on and removed from the machine.

#### *Snap Flask Work and Individually Serviced Machines*

49. For snap flask work, and work where the machine may be serviced by hand by either one or two men, it is possible to mount a molder's hopper directly over the machine and provide a gate on the lower part of the hopper of the proper size to fill the flask to be used on the particular job. In such cases, a hopper with three vertical sides and one inclined side is recommended. The angle of the inclined side being in any case more than  $60^{\circ}$ —preferably  $65^{\circ}$  or even  $70^{\circ}$ —where the height above the molding machine permits. Fig. 10 shows a typical installation.

50. Where larger work is concerned, and a hoist must be used to put the flask on the machine, it is not possible to put the molder's hopper over the machine. In such cases, it is frequently desirable to have the bin designed as above, with one or not more than two sloping sides, and a counterweighted chute to help direct the flow of the sand over the flask. In some of the heavier work, it facilitates operations to have the gate and chute operated independently by means of air cylinders. In all cases, the interior of these molder's hoppers should be free of projections, for instance, rivet heads, stiffeners, etc. See Fig. 11.

51. The use of vibrators to help in the discharge of sand from molders' hoppers is, in the main, unsatisfactory. If the vibrator is set to operate before the gate is opened, the tendency is to pack the sand more tightly in the hopper.

52. There is a tendency in ordinary steel hoppers for the damp molding sand to build up on the sides of the hopper. This is due to the natural tendency to form oxides on the surface of the bin, due to the moisture and to a certain amount of air which are present in the sand.

53. To overcome this, certain types of coverings have been resorted to, with some resulting improvement. The latest information indicates that certain lacquers which are impervious to moisture, give fairly good results, as also is the case where stainless steel liners have been used. In some instances, liners of plate glass (skylight glass reinforced with wire netting) have been used.

54. Near the seashore, this problem of the sand building-up on the sides of the hoppers is more serious than it is in the interior

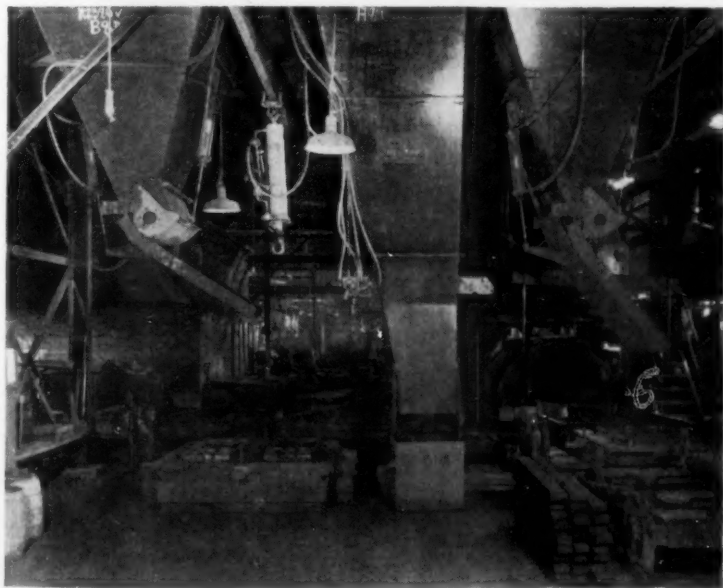


FIG. 11.—WELDED SAND HOPPERS OVER MOLDING MACHINES FOR LARGE WORK. THE HOPPERS ARE WELDED TO AVOID PROJECTIONS, SUCH AS RIVETS, ON THE INTERIOR OF THE HOPPERS.

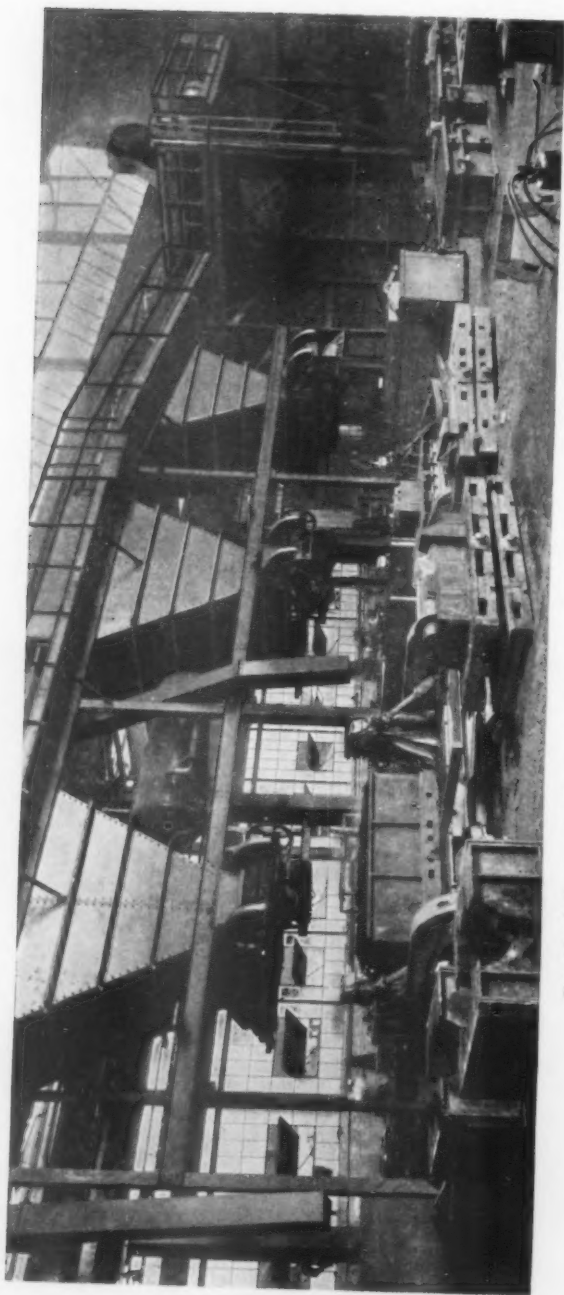


FIG. 12.—A BATTERY OF SINGLE FLASK FILLERS WITH HORIZONTAL APRON FEEDERS.

of the United States, due to the greater tendency to oxidation from the salt in the air.

### *Bin Design*

55. In general, all bins should be designed so that the stiffeners and columns carry the entire load, the steel plate being used merely to make the bin tight, and not to carry the load. Standard design for structures applies generally to bins, although for the most part, no account need be taken of wind pressure or resistance, as most of the bins are placed inside buildings. However, care should be taken that the bin structure be designed to meet the condition of loading unequally, which frequently happens in sand plants. One end of the bin may be filled to the top, while the other end may seemingly contain nothing. This frequently produces critical distortion stresses.

56. Large molders' hoppers are frequently provided in heavy molding work, and it has been found desirable to place apron feeders under such hoppers. In some cases, as many as three aprons, having widths of 42-in., have been used to fill a flask in a short time. This particular flask had a length of 18-ft. and a width of about 4½-ft. This flask is filled by the equipment in about 6 sec. Such hoppers can be arranged with minimum angles and can be emptied quite satisfactorily. An installation of this type is shown in Fig. 12.

57. The foregoing is only a brief discussion of a problem which concerns every engineer charged with the design of bins and hoppers for service in foundries of whatever class.

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## DISCUSSION

*Presiding:* R. D. BRIZZOLARA, American Steel Foundries, Chicago, Ill.

J. R. ALLAN<sup>1</sup> (*Written Discussion*): Mr. McKinnon's paper on the cooling and storage of foundry sands should be of extreme interest to all of us. This paper is a direct indication that equipment vendors are beginning to find out some of the principles involved in the handling, cooling and conditioning of sand.

The sand handling system should be designed scientifically and not simply consist of a lot of running belts and conveyors, elevators, screens, aerators, and many times, useless equipment that accomplishes no good purpose. In our own company, we have purchased hundreds of thou-

<sup>1</sup>Assistant Manager, Industrial Engineering and Construction, International Harvester Co., Chicago, Ill.

sands of dollars worth of sand handling equipment, and outside of conveying the sand to a storage tank, no thought has ever been given as to how to cool the sand. The result was that we were confronted with hot sand conditions which made it necessary to get into the research of sand cooling.

A little research will indicate that the problem is quite simple if we consider the sand handling unit as a refrigerating system.

Today, we can mathematically calculate a sand cooling system with accuracy. We must start out, of course, with known factors, as Mr. McKinnon has ably discussed in his paper, *i. e.*, the known conditions: the weight of sand to be handled per unit of time, the initial temperature of the sand as shaken out, the average moisture content of the sand as shaken out, and an assumption of the desired temperature of the sand to be returned to the sand storage tanks. This latter temperature should be in the neighborhood of 100°F.

The production foundryman can help himself considerably in his sand cooling problem. We are of the opinion that it is a fallacy to attempt to reduce the amount of sand in the mold per pound of metal poured, unless dry molds are being made. The more sand in the mold per pound of metal poured, the greater the remaining moisture content in the sand as shaken out, and this moisture content minimizes the amount of water to be applied later in the refrigerating or evaporating process. It is our opinion that the relation of sand to metal poured per mold should not be less than about 4 to 1. When this ratio is decreased, additional difficulties are experienced not only in the cooling of the sand, but we are likely to be confronted with flask warpage and also the disagreeable task of handling hot flasks, etc.

To design a successful sand cooling or refrigerating system, the rule or formula to be applied for the amount of water to be added to the sand shaken out in order to obtain the desired tank storage temperature, is as follows:

$$\text{Specific Heat of Sand} \times \text{Weight of Sand} \times \text{Temperature Drop Required.}$$

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*Heat Required in B. t. u. to Evaporate 1 lb. of Water to a Practical Final Moisture Content.*

Foundry conditions vary with each individual installation. The first element involved is the average temperature of the sand shaken out of the molds, and the second condition is the desired temperature in the storage tank. For most practical results, this should be 100°F. The specific heat of sand is 0.195, which will give more accurate results than the 0.24 specific heat figure given in the author's paper. The heat required to evaporate 1 lb. of water theoretically from and at 212°F. at atmospheric pressure is 1150.4 B. t. u. However, all moisture cannot be eliminated in the cooling process and the remaining moisture content

is about 1 per cent or slightly less, so that the divisor in the formula should be 1101 B. t. u.

We feel there is a cardinal principle to be applied in the application of the water and the subsequent handling of the sand on its way to the storage tank. Our best results have been obtained by applying the required quantity of water on the shakeout sand conveyor as near the shakeout operation as possible. Where the sand is over 212°F. when shaken out and water is applied, the water will immediately start to evaporate from the hot sand because it is above the boiling point of water and such evaporation immediately begins to lower the temperature of the sand. Furthermore, the water has an opportunity to permeate to some extent into the sand on the conveyors. This water has a tendency to be distributed throughout the sand as the sand leaves the conveyor and goes to the vertical elevators to convey it to the sand cooling barrel. By the time the sand has reached the sand cooling barrel, most of the moisture has been driven off above the boiling point of water, namely 212°, and the remaining water in the sand is fairly well mixed into the sand in a vaporized form.

The sand then enters a long rather large-diameter cooling barrel. The greater portion of the length of this barrel is composed of solid steel plates with lifting flights or elevators located longitudinally throughout the length of this barrel so that as the barrel is revolved, the sand is picked up and repeatedly dropped to the bottom of the barrel, exposing the individual sand particles to the flow of air through the barrel. The discharge end of the barrel should consist of a short screen section, through which the sand is dropped into the storage tanks. The use of the screened section in the discharge end of the barrel will eliminate chunks of cores, tramp iron, and other foreign material from entering the sand storage tank.

Let it be assumed that the sand has a temperature of 600°F. as shaken out. It will require 8.86 lb. of water per 100 lb. of sand to cool to 100°F. The amount of moisture which will be evaporated on the conveyor before reaching the cooling barrel is 6.88 lb. giving off 183 cu. ft. of moisture vapor. There remains 1.98 lb. of moisture to be evaporated in the barrel having a vapor volume of 53 cu. ft.

The application of air to the sand cooling barrel is extremely important. We have learned from our industrial furnace applications throughout our operations, that the contra-flow principle of air movement is most successful and this is the principle of air movement to apply in a sand barrel. In other words, the cold air, or room temperature air, should enter the barrel at the end of the barrel where the sand discharges into the tank. The flow of air should be through the barrel and exhausted at the end of the barrel where the sand enters. The reason for this can be very readily seen. Assuming 70°F. room air entering the barrel with 50 per cent relative humidity, this air has the ability to pick up only 52.25 grains of moisture per pound of air. As the air becomes heated by the heat released from the materials within the

barrel, the warmer air has a greater capacity for picking up larger quantities of moisture, or, in other words, the moisture vapor that is being released and evaporated from the sand. For instance, 100°F. air will pick up 249.05 grains of moisture per pound, 150°F. air will pick up 1432.71 grains of moisture and 200°F. air will pick up 15014.85 grains of moisture per pound.

Another reason why it is so essential to apply the water immediately after shaking out the molds is to get the greatest of cooling effect possible on the conveyors and elevators prior to the sand entering the barrel. By getting this moisture release ahead of the barrel, the volume of exhaust from the barrel necessary to remove the moisture vapor that is given off by the sand within the barrel, is reduced. This keeps the air velocities down to a point where the bond and usable fines will not be removed from the sand. The velocity of air through the barrel should not exceed 100 ft. per minute, and it is always well, even with this low velocity, to provide an expansion chamber at the discharge screen end of the barrel to greatly lower this velocity so that any usable fines and bond picked up will drop into the sand storage tank.

A properly designed sand cooling system should reduce the moisture content of the sand to under 1 per cent. However, this will vary some, depending upon the initial temperature of the sand, and cannot be controlled absolutely.

It is extremely desirable that the tank storage sand temperatures be not over approximately 100°F. If the moisture content is brought down to 1 per cent or slightly less, it is usually possible to reduce the amount of tank storage capacity about 50 per cent, for the reason that under these conditions, the sand will not stick to the sides of the tank or bridge. Thus all the sand in the tank is usable.

The situation existing in storage tanks in the past, has been that only  $\frac{1}{2}$  or  $\frac{1}{3}$  of the sand has been in active use. This is because the sand has gone into the tanks hot and with a quite high moisture content, with the result that it hangs in the tanks and, unless broken out, never gets into the sand system.

Assuming that the sand in the storage tanks has been reduced to approximately 100°F., the next operation of mulling will further reduce the sand temperature another 10 or 12°. This will bring the temperature down to about 90°F. Usually there is not much cooling effect beyond the mullers unless aerators are used, and the use of aerators will depend largely upon the quality of sand conditions required. Aerators will, of course, further reduce the temperature.

The method of applying water to the sand shaken out of the molds on the conveyors is quite important. There are a number of ways of doing this, but the sand on the conveyors should be plowed and scraped into a rather definite shape so that with a proper device that will ride on top of the sand, the proper proportion of water will be distributed over the hot sand, depending upon the depth of the sand on the belt.

While an electric eye control can be used for this, usually steam conditions make the functioning of an electric eye rather erratic and it can better be controlled by a mechanical device. It is necessary that the discharge orifices and the water pressure be constant for a given set of conditions, then the water will be proportioned according to the depth of sand on the belt.

MEMBER: We have experienced almost all the points Mr. McKinnon has covered in our mills. At the present time, our keenest problem is in connection with the cooling of the castings. I would like to hear Mr. McKinnon comment on the importance of the baffles used in the mills and whether they can be reduced in length without seriously affecting the efficiency of cooling?

MR. MCKINNON: I doubt if it is possible to do that. I would just like to say a word about Mr. Allan's remarks. In the first place, in all of these cases we usually leveled the sand so that we had a definite amount before we put water on it. If we did not do that, we used the mechanical type of valve control, but we have found that it is not satisfactory where there is a great variety of work. For instance, we will get one mold with the ideal 4 to 1, or 5 to 1 sand to metal ratio and the next mold would be one which is only 2 to 1. Taking care of those ups and downs has been the reason for recommending the averaging thermometer. We have always added the water as close to the shakeout as practicable, and we have gotten the air into the sand after it has had the initial steam forced out of it by the temperature. But so far as cooling is concerned, the baffles are a necessary evil and they take a certain amount of room, and the velocity of air forms a very important factor in the control of proper cooling. But a rig of that kind cannot be overloaded without getting some bad results.

A. H. LAUER:<sup>2</sup> We run over our belts something like 60 tons of sand per hour. Our belts are rather slow. For a time we added water, but we discontinued that. At the present time, we are confronted with hot sand, and the only way we have of taking care of this is by alternating the molds. Instead of bringing the molds back immediately after they are poured, we set that heat aside and bring in the next one, and in that way have had fairly good cold sand.

CHAIRMAN BRIZZOLARA: The author referred to sand temperature from molds in the order of 500° to 900°F. Did he refer to the average temperature of all the sand in the mold or just that portion close to the casting?

MR. MCKINNON: That is the average temperature in the mold. We shake it out as quickly as possible and put thermometers in it in three or four places and get the average temperature.

J. R. ALLAN: You apply the water in the barrel and that is controlled by an averaging thermometer?

<sup>2</sup> Assistant Works Manager, American Steel Foundries, Granite City, Ill.

MR. MCKINNON: That is one type used on high temperature work only. If we get a cold sand we shut off the water immediately.

J. R. ALLAN: Suppose your barrel is hot?

MR. MCKINNON: The place where we use an averaging thermometer is over the flow of sand on the conveyor. On this arrangement, we nearly always insist upon an apron conveyor where we get a depth of sand 4 or 5-in. in depth, then we arrange to plow that so we get little streams in the sand.

J. R. ALLAN: You depend upon averaging on the conveyor belt rather than temperature discharge.

MR. MCKINNON: The device we have is based upon measuring the temperature of the air at the outlet and controlling the air at the inlet. That we have only applied to hot shakeout cores. For instance, in one installation where the average temperature is over 1,000°F. at the point where the cores are shaken out at a rate of about 5 tons an hour, we dropped that to 200 to 230°F. Of course, there is no danger of mud at that point. That system is only for the patented device we have worked out for very hot sand, but the averaging thermometer is used on sands that run way down. We can arrange the shut-off so that the moisture is cut off absolutely at, say 190 or 180 or 200°F.

J. R. ALLAN: On your first run you put the water on?

MR. MCKINNON: There would not be water on it. It is all right so long as we have the same mold coming hour after hour. The device can be set and the average temperature secured and that is perfectly satisfactory. You can measure the water in that case. On a job with what you mentioned as the ideal, four to one, and I agree with you that is about the ideal ratio of sand to metal, we are not troubled very much when we get to that sort of temperature. But where the ratio is two to one or one and one-half to one, as on car wheel work, the temperatures are very high. There you cannot even get water into the sand. It touches the surface and explodes. You are almost at the critical temperature of the water at that time, and you get a violent amount of steam scattered all over the place and it is very difficult to handle. We like to put sand of that temperature in a cylinder. We usually make the cylinder do the last job. Also, we have found using an aerator is of great help. As a matter of fact, that wheel will normally take out one-half of 1 per cent moisture when it is coming in at fairly high temperature—and you know what that amount drop in temperature would be.

J. R. ALLAN: At what air velocity?

MR. MCKINNON: That depends upon the nature of the sand. It we are using sand coarser than 70 mesh, we run the velocities up to 200 or 300 ft. per min. As we get into fine sand, we have to get way down to 100 or 150 ft. per min. When using 0 or 00 sand, it must be reduced below 100 ft. per min.

J. R. ALLAN: How do you avoid the loss of fines on those higher velocities?

MR. MCKINNON: If you keep the velocities down in the barrel, we do not find much trouble with losing fines. In fact, most every foundry wants to lose some fines. We have found that out. They would like to get rid of them. We have a problem now where a man wants to lose everything under 150 mesh.

H. L. MCKINNON (*Author's Written Closure*): With further reference to discussion, we wish to call attention to the discrepancy between specific heats as given by Mr. Allen, and as used in the writer's paper. The writer did not have the authorities at hand during the discussion in Chicago, but presents herewith tables of specific heat of silica from three different authorities, namely Hodgman and Lange, Hougen and Watson, and International Critical Tables.

Table 1

## SPECIFIC HEAT OF SILICA

| °C   | °F   | <i>Chemical Rubber<br/>Handbook—1931<br/>Hodgman—Lange<br/>B.t.u. per lb.</i> | <i>Industrial Chem.<br/>Calculation—1931<br/>Hougen—Watson<br/>B.t.u. per lb.</i> | <i>International<br/>Critical Table<br/>B.t.u. per lb.</i> |
|------|------|---|---|--|
|      |      |   |   |  |
| 0    | 32   |   | 0.165   | 0.166  |
| 100  | 212  | 0.237   | 0.205   | 0.204  |
| 200  | 392  | 0.242   | 0.235   | 0.232  |
| 300  | 572  | 0.246   | 0.250   | 0.254  |
| 400  | 752  | 0.2504  | 0.260   | 0.270  |
| 500  | 932  | 0.255   | 0.265   | 0.290  |
| 600  | 1112 | 0.259   | 0.270   | 0.271  |
| 700  | 1292 | 0.264   | 0.274   | 0.273  |
| 800  | 1472 | 0.268   | 0.275   | 0.276  |
| 900  | 1652 | 0.272   | 0.278   | 0.278  |
| 1000 | 1832 | 0.277   | 0.280   | 0.281  |

It should be remembered that our operating temperatures during the cooling of sand lie between 100 and 700°F., therefore, the portion of the table used is limited to this range. The average of the range for specific heats given by three authorities quoted is as follows:

|                                     |       |
|-------------------------------------|-------|
| Hodgman-Lange .....                 | 0.243 |
| Hougen-Watson .....                 | 0.237 |
| International Critical Tables ..... | 0.24  |

These are, of course, made for silica, which is the basis of practically all molding sands. However, it should be stated that if there is considerable quantity of clay in the molding sand, the specific heat would vary, as the specific heat of various grades of clay varies noticeably and it would be necessary to have the description of the clay and its percentage to determine the specific heat of the combination of silica and clay. We have confined our calculations to silica as being more definite, and therefore capable of direct computation.

One other item which deserves notice is the figure to be used for the effect of the evaporation of one pound of water in reducing the temperature of the sand. It is necessary to specify the temperature of the water as applied to determine the proper figure. For instance, if water is at 60°F., the total heat above that point is 1122.4 B. t. u. per lb.; and part of the evaporation takes place below 212°F. Making the calculation at 150°F., the total heat above 60°F. is 1,097 B. t. u. per lb. So that we have, in general, used the figure of 1100 B. t. u. in our calculations.

Our tests also have shown that in the cooling process, we get the molding sand considerable below 1 per cent of moisture, and in the several tests made, the sand was practically bone dry. We use 60°F. as temperature for water, since it is close to the operating conditions observed in at least 90 per cent of the foundries in which we have had occasion to test it.

## Notes on the Clay Bonding of Molding Sands

BY HARRY L. DAASCH\*, BURLINGTON, VT.

### Abstract

*The author discusses data on bond strength and heat of wetting values. Bentonite-sand mixtures and natural sands were studied. Results of various conditions of mixing, mulling and heating are reported. The importance of mulling water quantity is discussed and consideration of an optimum mulling moisture for sand preparation processes is proposed. Curves and calculations submitted indicate a general relationship between strength and heat of wetting which seems to apply to sand-bentonite mixtures. A critical analysis and comparison of the data and past literature of correlary fields is offered. Rigorous mathematical application of heat of wetting theory is not recommended, for the present, for natural molding sands. Similar shortcomings of base-exchange or other surface phenomena, as applied to natural sands, is claimed and discussed. The lack of a commercially useful method of studying the bonding effectiveness of A.F.A. clay substance is alluded to. However, the heat of wetting is offered as a means of evaluating bond substance efficiency. Specific cases are cited wherein heat of wetting theory and calculations may be used as a measure of the efficiency of bond substance. In the case of bentonite-sand mixtures, reasons for the degree of bond effectiveness as indicated by heat of wetting are discussed in terms of mulling moisture, temper moisture and proportion of bond.*

1. Clay has proved a useful bonding material for molding sands. In recent years, detailed studies have been made and reported in connection with this bonding substance. The purpose of the present paper is to offer certain new laboratory studies of clay bond materials and to discuss bonding properties in terms of laboratory testing characteristics.

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NOTE: This paper was presented at a Foundry Sand Research Session at 44th A.F.A. Convention, May 8, 1940, Chicago, Ill.

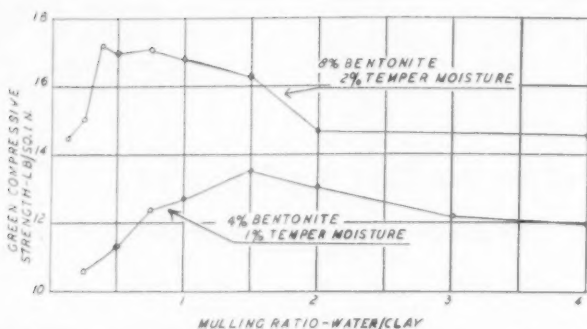


FIG. 1.—VARIATION OF GREEN COMPRESSION STRENGTH WITH MULLING RATIO OF WATER TO CLAY.

#### MULLING WATER QUANTITY AND STRENGTH RELATIONSHIPS OF 4 AND 8 PER CENT BENTONITE MIXTURES

2. In the discussion of a paper by Briggs and Morey the present writer emphasized the importance of the amount of water added during the mulling of bentonite-sand mixtures. Fig. 1 is reproduced from that discussion. Data represented were secured from mixtures of 4 and 8 per cent bentonite with white silica sand. These base mixtures were mulled in a laboratory-size muller for 7 min. but different proportions of mulling water were used in different batches. The quantity of mulling water will henceforth be referred to as mulling ratio; such ratio being water by weight to the clay content by weight.

3. The mulled products were dried carefully at 220°F. for one hour and then retempered as noted on the curves. Strength data were secured according to A.F.A. Standards.<sup>2\*</sup>

4. It is evident that the strength of both the 4 and 8 per cent mixtures varied with the mulling ratio which was the only variable.

5. Data, in addition to that shown in Fig. 1, have been secured for the same 4 and 8 per cent bentonite mixtures which were mulled as already described with varying mulling ratios. All mulled mixtures were dried at 220°F. as before and then tempered to varying temper moisture quantities. Information on green strength properties is shown in Figs. 2 and 3.

6. As an aid to comparison with later data and curves, Figs. 2 and 3 have been plotted to a semi-logarithmic basis. The primary effect of such plotting is a spreading and separating of the low mulling ratio values. There is no influence on the height of the

\* Superior figures refer to References at end of paper.

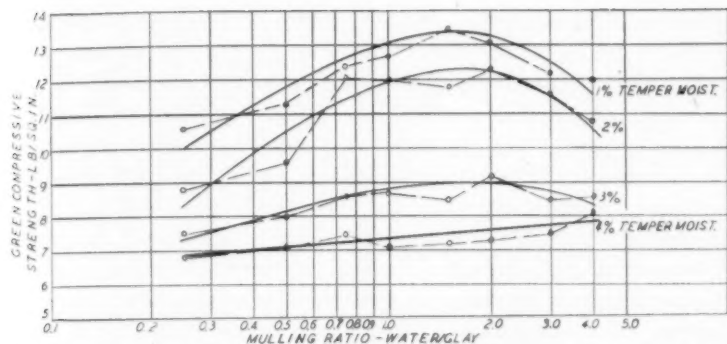


FIG. 2—RELATIONSHIP OF GREEN COMPRESSIVE STRENGTH TO MULLING RATIO FOR 4 PER CENT BENTONITE MIXTURE.

curve which denotes strength, and visual perspective of strength by virtue of curve height is not disturbed. Dotted, actual point-to-point and full-line, idealized curves are drawn.

7. Each curve of Figs. 2 and 3 pertains to a specified temper moisture content. Added data, which were secured but are omitted for the sake of brevity and clarity, indicated that the optimum green strength temper moisture (for all mulling ratios) was approximated at 1 and 2 per cent moisture for the 4 and 8 per cent bentonite mixtures respectively. These approximate optimum values happen to be the temper moisture contents for the data originally reported and shown as Fig. 1.

#### Strengths vs. Mulling Ratios

8. The fact illustrated by both Figs. 2 and 3 is that there is

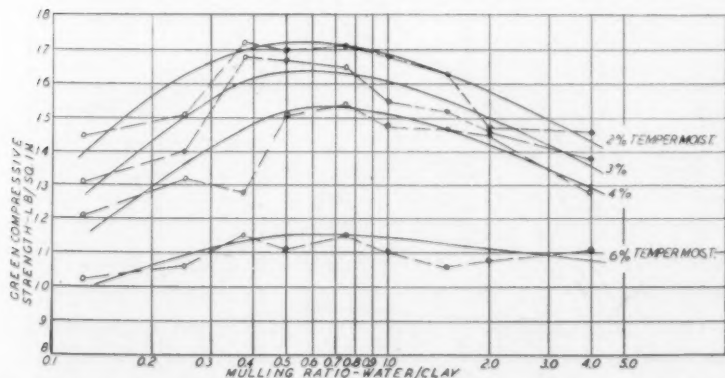


FIG. 3—RELATIONSHIP OF GREEN COMPRESSIVE STRENGTH TO MULLING RATIO FOR 8 PER CENT BENTONITE MIXTURE.

an optimum mulling ratio (optimum refers here to maximum green strength.) The optimum ratios are more clearly evident and pronounced as optimum temper moisture quantities are used. When the temper moisture is much greater than optimum, the mulling ratios have less significance. In other words, the past conception of an optimum temper moisture is still to be retained but the idea of optimum mulling moisture must be added. Thus for the 4 per cent bentonite mixture, a 1 per cent temper moisture is optimum. The maximum green strength for such a temper condition will not be realized unless the previous mulling has been carried out with a mulling ratio of about  $1\frac{1}{2}$ ; i. e., 6 per cent mulling water.

9. Somewhat similar facts are shown by Figs. 4 and 5, which refer to relationships of dry strength with mulling ratio. Again, both point-to-point and idealized curves are shown.

10. Dry strength increases with increases in the temper moisture throughout the range studied. The quantity of mulling water becomes less significant as a factor of control of the dry strength as temper moisture is decreased. Decided variation in dry strength results as the mulling ratios are varied and when high percentages of temper moisture are used.

11. The mixtures under consideration are essentially bentonite, sand and water combinations. Water additions, as temper

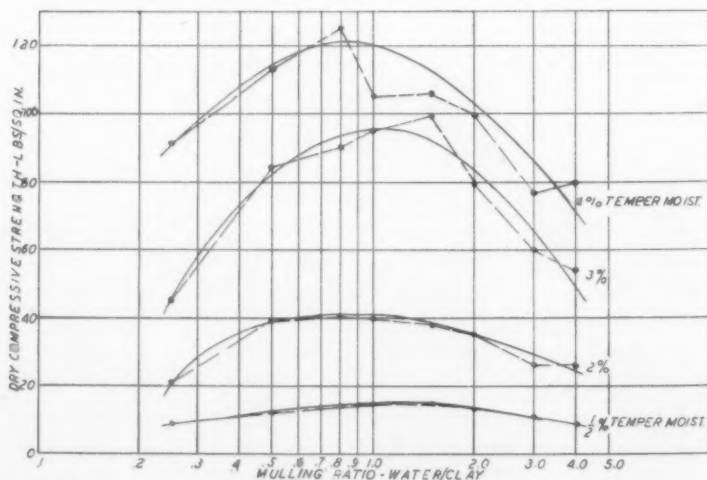


FIG. 4—RELATIONSHIP OF DRY COMPRESSIVE STRENGTH TO MULLING RATIO FOR 4 PER CENT BENTONITE MIXTURES.

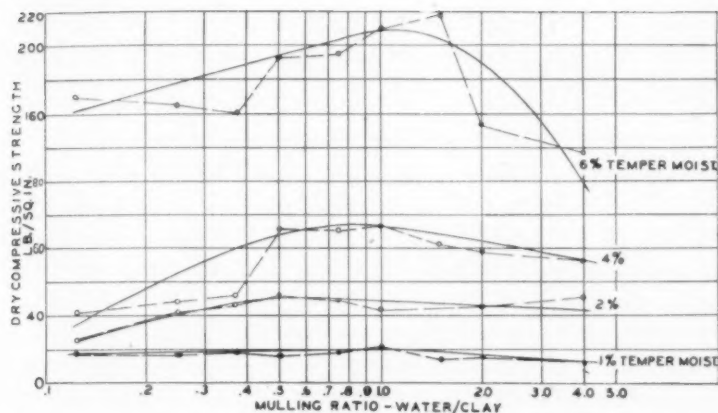


FIG. 5—RELATIONSHIP OF DRY COMPRESSIVE STRENGTH TO MULLING RATIO FOR 8 PER CENT BENTONITE MIXTURES.

moisture, are intended to form with the bentonite as a binder or bond by virtue of which the strength of the mixture is attained.

12. It is well known that the mode of distribution of the clay around the sand grains is important in the final determination of strength. The physical aspects of the mulling process are self-evident. That a most effective condition of clay enveloped sand particles might result from some specific mulling water ratio, is likewise expected.

13. The thesis of Messrs. Briggs and Morey<sup>1</sup> that simple bentonite-sand-water mixtures may, by simple variations in the proportions of the components, be made to exhibit many different properties, may therefore be extended to include the process of mixing these components. Mulling water ratios have been specifically studied and are reported here. It is evident that data, whether for laboratory investigations or in connection with shop control of sand heaps, should include information on the mulling ratio. As indicated by Briggs and Morey, the term "optimum" temper moisture may refer to a maximum of any one of several physical characteristics of the molding sand. Consideration of "optimum" mulling moisture from the viewpoint of these several properties is therefore indicated. It should also be noted that the optimum mulling moisture here reported is higher than optimum temper moisture. This may be unfortunate since tempering control follows sand preparation and mixing. A practical compromise may be secured by mulling make-up or added clay with a portion of

the sand and with the higher mulling moisture. This product may be remixed with the main dry heap so that a lower moisture range may be secured.

#### HEAT OF WETTING PHENOMENA

14. The behavior of sand-clay-water mixtures is evidently one in which surface contacts of the mixture components are involved. If, for the purpose of discussion, there is acceptance of the generally made statement that the strength values, such as are under consideration, are primarily determined by the bond substance; then, variations shown in Figs. 2 through 5 are due primarily to the clay-water combinations. With the further thought that surface contacts are paramount, the simple process of wetting the clay by the water becomes a logical point of focus.

15. The manifestations of heat evolution during the wetting of a fine powder is a known, although not well understood, phenomena. Both the phenomena and the quantity of heat evolved have been referred to as the *heat of wetting*. While the explanation of this heat evolution is not entirely clear, several theories have been proposed in the many references in literature.

#### Theories

16. A review of the theories of heat of wetting has been made by Sherwood<sup>8</sup>. Bouyoucos<sup>3</sup> suggests that the evolution of heat during wetting is "caused by a change in state of the liquid to that of a solid or semi-solid state."

17. Lamb and Coolidge<sup>4</sup> consider heat of wetting to be the result of great compression of the layers of the molecular films of the liquid which surround the small particles of powder. The report of these men shows the heat of wetting to be directly proportional to the heat of compression of the various liquids used. In other words, the liquid is attracted by a force characteristic of the solid and such force simply acts to compress the liquid. These same investigators consider the general process of wetting to be one of adsorption and they compare it to the adsorption of a gas by charcoal. They report "The process of adsorption of a gas can be pictured as taking place in two steps; first, the compression of a gas to such a point that liquification ensues and, second, a further compression of this liquid by the adhesive forces of the adsorbent." A similar theory seems to be entertained by Washburn<sup>5</sup>.

18. Patrick and Grim<sup>6</sup> suggests the change in surface energy theory. According to this theory, there is a loss of surface energy of the solid being wetted. This loss must be evident as a gain in energy by the system solid plus liquid. The energy involved is evident further by the increase in temperature of the entire mass of powder and surrounding liquid mixture. These men apparently visualize the solid particle as being wrapped by a surface layer of molecular thickness which surface is decreased during immersion since "there can be no water to water interface."

19. In any event, the heat of wetting seems definitely to be a surface characteristic. Hoseh<sup>7</sup> very aptly sums the situation when he says; "The evolution of heat on wetting certain powders is a display of energy inherent to their surface properties. It is immaterial whether one accepts the theory of physical absorption, or polar absorption, or change of surface free energy; surface relationships are concerned."

20. The production of clay-water mixtures of a molding sand may thus be considered as establishing a very likely situation for the display of the heat of wetting phenomena.

#### HEAT OF WETTING OF 4 AND 8 PER CENT BENTONITE MIXTURES

##### *Apparatus and Procedure*

21. Accordingly equipment was developed for the purpose of studying heat of wetting quantities. Such equipment has been known and used by soil physicists and physical-chemists; but, in the interests of simplicity and because of specific peculiarities of molding sands, it was felt best to develop equipment especially suited to the needs of the problem at hand. The construction of the equipment is essentially due to and has been described by Sherwood<sup>8</sup>.

22. Briefly, a pint size, standard, vacuum thermos bottle was covered with magnesium-asbestos insulation material and the whole incased in a two-part wooden container. The bottle opening was accessible for the admission of the test samples and for the insertion of the Beckman thermometer whereby temperature data was secured.

23. The water equivalent of the entire equipment was determined by appropriate means. During the use of the calorimeter, care was taken to eliminate extraneous influences. Water to be

used in the calorimeter, test samples, and the calorimeter equipment was kept in a constant temperature room.

24. Fifty gram samples of sand-clay mixtures were used in most tests. All samples were given a preliminary 12 hr. drying period at 216-218°F. to drive off excess, free moisture. Uniform temperatures of all material and equipment were attained during the following 12 hr. The final mixing of sand-clay mixture with the water in the calorimeter results in a rise of temperature which may be observed by means of the Beckman thermometer. The maximum rise in temperature is reached in approximately 30 min. The heat of wetting can be calculated easily from the temperature rise, sand weight, water weight and water equivalent of the equipment data.

25. Since the laboratory equipment involved metric units, results are here quoted in calories per gram.

#### *Heat of Wetting of Bentonite-Sand Mixtures*

26. Each of the variously-mulled mixtures of 4 and 8 per cent bentonite were tested as outlined in the preceding paragraphs and results are shown in Table 1. It will be remembered that various mulling water ratios were used in the preparation of the mixtures. Further, it should be recalled that free moisture after mulling was driven off by drying before the heat of wetting determinations.

27. Graphical presentation of the data is offered in Fig. 6. Mulling ratios are plotted to the same logarithmic scale as are Figs. 2 through 5.

28. Curves *A*, *B* and *C* are included in Figs. 6. *A* and *B* pertain to the 8 and 4 per cent bentonite mixtures respectively. Heat of wetting in calories per gram of mixture are thus shown. Curve *C* involves data from both mixtures and on a calories per gram of bentonite basis. All three curves have been drawn as equivalent lines. Whether experimental error or unknown influences are most responsible for the deviations of experimental data from curves is unknown. The general trend, especially as established by curve *C*, warrants the conclusion that mulling water ratios are an important, controlling factor in the heat of wetting values.

29. The heat of wetting per gram of bentonite seems to reach a maximum at a mulling ratio something greater than unity. Tests

Table 1

## HEAT OF WETTING OF 4 AND 8 PER CENT BENTONITE MIXTURES

| Mulling<br>Water<br>Ratio. | Heat of Wetting                 |                         |                                   |                         |
|----------------------------|---------------------------------|-------------------------|-----------------------------------|-------------------------|
|                            | Calories per gram<br>of Mixture |                         | Calories per gram<br>of Bentonite |                         |
|                            | 4 per cent<br>Bentonite         | 8 per cent<br>Bentonite | 4 per cent<br>Bentonite           | 8 per cent<br>Bentonite |
| $\frac{1}{8}$              |                                 |                         | 0.713                             | 8.6                     |
|                            |                                 |                         | 0.745                             | 9.3                     |
| $\frac{1}{4}$              | 0.424                           | 10.6                    | 0.768                             | 9.6                     |
|                            | 0.400                           | 10.0                    | 0.770                             | 9.6                     |
| $\frac{3}{8}$              |                                 |                         | 0.816                             | 10.2                    |
|                            |                                 |                         | 0.848                             | 10.6                    |
| $\frac{1}{2}$              | 0.424                           | 10.6                    | 0.896                             | 11.2                    |
|                            | 0.448                           | 11.2                    |                                   |                         |
| $\frac{3}{4}$              | 0.476                           | 11.9                    | 0.952                             | 11.9                    |
| 1                          | 0.476                           | 11.9                    | 0.952                             | 11.9                    |
|                            | 0.540                           | 13.5                    | 1.110                             | 13.9                    |
| $1\frac{1}{2}$             | 0.448                           | 11.2                    | 1.008                             | 12.6                    |
| 2                          | 0.448                           | 11.2                    | 1.056                             | 13.2                    |
| 3                          | 0.500                           | 12.5                    |                                   |                         |
| 4                          | 0.528                           | 13.2                    | 1.032                             | 12.9                    |

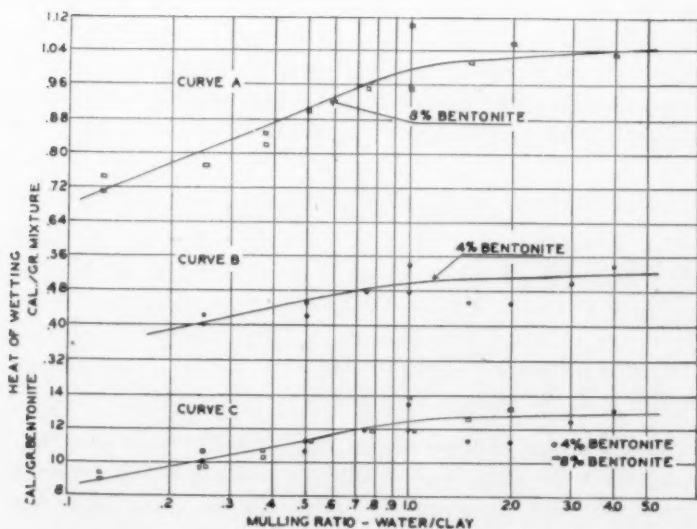


FIG. 6—RELATIONSHIP OF HEAT OF WETTING TO MULLING RATIO FOR 4 AND 8 PER CENT BENTONITE MIXTURES.

made with mulling ratios as great as 20, indicate no further increase in the heat of wetting value. The approximate maximum value may be simply stated as: Equation (1) — Heat of Wetting per gram bentonite = 13 calories.

#### CORRELATION OF STRENGTH AND HEAT OF WETTING FOR 4 AND 8 PER CENT BENTONITE MIXTURES

30. Reference to Figs. 2 and 6 suggests that the mulling water ratio is a similar influence in determining the occurrence of maximum strengths and heat of wetting values.

31. The maximum strengths occur at about the same mulling ratio as does the maximum heat of wetting. It should be recalled that the ideal molding sand mixture may be visualized as sand grains, each enveloped with a thin layer of bonding clay. One function of mulling is to effect a distribution of the clay. As already stated, such distribution obviously is influenced by the quantity of mulling water. Interestingly, the mulling water ratio also influences the heat of wetting. Thus, the effectiveness of the enveloping of sand grains by bentonite may be suspected from the viewpoint of heat of wetting values.

32. These facts may prove especially valuable. So far as the writer is aware, no similar correlations have been reported for other physical or physical-chemical phenomena utilized in the fundamental studies of molding sand bonding characteristics. Further studies along these lines may also yield fundamental information on the mechanism of bonding.

#### HEAT OF WETTING OF HAND AND MACHINE MULLED MIXTURES

33. Another aspect of this work is indicated by Table 2. Heats of wetting are tabulated for three different methods of making bentonite-sand mixtures. Bentonite percentages from 0 to 100 per cent are indicated with Method A (Dry hand mixing), Method B (Hand mixing with water to clay ratio of 1:1), and Method C (Machine mulling mixing with water to clay ratio of 1:1).

34. The hand mixing was accomplished by hand scooping the mixture from the metal work table top, rubbing between the palms of the hands, and repeating the operations when the first handful had been gradually lost back to the table. Machine mulling was the regular 7 min. period reported for previous tests.

Table 2

## HEAT OF WETTING FOR DIFFERENT METHODS OF MIXING BENTONITE-SAND MIXTURES

—Heat of Wetting, Calories per Gram Mixture—

| Per Cent<br>Bentonite | A             | B                            | C                            |
|-----------------------|---------------|------------------------------|------------------------------|
|                       | Hand          | Hand                         | Machine                      |
|                       | Mixing<br>Dry | Mixing<br>Water Ratio<br>1:1 | Mixing<br>Water Ratio<br>1:1 |
| 0                     | 0             | 0                            | 0                            |
| 4                     | 0.39          | 0.55                         | 0.58                         |
|                       | 0.37          |                              |                              |
| 8                     | 0.71          | 0.98                         | 1.03                         |
| 12                    | 1.00          | 1.34                         | 1.32                         |
| 20                    | 1.90          | 2.14                         | 2.27                         |
| 50                    | 6.13          | 5.95                         | 5.92                         |
| 100                   | 11.54         | 11.50                        | 11.64                        |

35. It is evident from data for methods *A* and *B* that the water used during the mixing is a vital factor in the heat of wetting for mixtures low in bentonite. The difference between *A* and *B* columns in Table 2 is not so significant for concentrated bentonite proportions. Obviously, the question of clay distribution over sand particles becomes of less importance in the high bentonite mixtures. The differences for variation in the mechanical phases of wet mixing are shown by columns *B* and *C*. Differences are within the experimental error. So far as heat of wetting is concerned, the data simply emphasizes the importance of the water-clay ratio and indicates the lesser importance of the mechanical details of mulling.

## EFFECT OF OVEN HEATING ON HEAT OF WETTING AND STRENGTH OF SAND-BENTONITE MIXTURES

36. A molding sand was prepared of white silica sand and 10 per cent bentonite. The mixture was mulled in the laboratory muller for 7 min. with a 2 per cent water addition; a mulling ratio of 0.2. To secure variable bond strength, portions of the mixture were heated for a period of 2 hr. at several different temperatures up to 1400°F. Green compression strength and heat of wetting information was secured on such heated samples and results are shown in Table 3 and Figs. 7 and 8.

37. The expected decrease in strength with increase in the temperature of heating is apparently accompanied by a similar decrease in the heat of wetting.

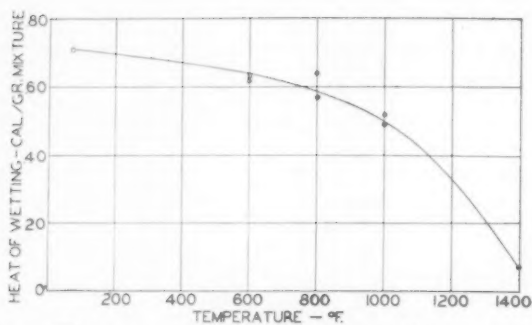


FIG. 7—HEAT OF WETTING OF 10 PER CENT BENTONITE MIXTURE AFTER HEATING TO VARIOUS TEMPERATURES.

Table 3

HEAT OF WETTING OF HEATED SAND-BENTONITE MIXTURES

| Temperature<br>of<br>Heating, °F. | Green<br>Compressive Strength*,<br>lb. per sq. in. |      | Heat<br>of Wetting,<br>Cal. per Gram<br>Mixture |      |
|-----------------------------------|--|------|---|------|
| Original                          | 13.6   | ...  | 0.70  | ...  |
| 600                               | 15.7   | 15.6 | 0.62  | 0.63 |
| 800                               | 13.2   | 14.3 | 0.57  | 0.64 |
| 1000                              | 12.2   | 12.2 | 0.49  | 0.52 |
| 1400                              | 1.4  | 1.5  | 0.07  | ...  |

\* 6 per cent temper moisture.

38. Fig. 9 indicates the relationship between heat of wetting and green compression strength. Data from Table 3 for the 10 per cent bentonite mixture and from Figs. 2, 4 and 6 for the 4 per cent bentonite mixture are shown.

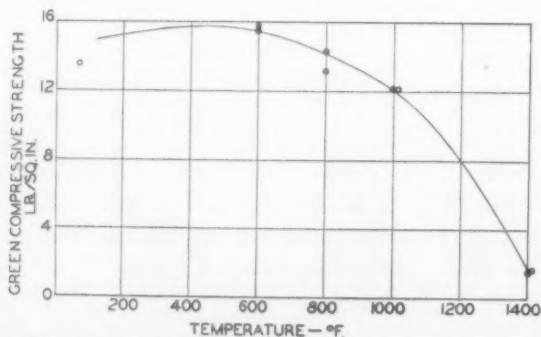


FIG. 8—GREEN COMPRESSIVE STRENGTH OF 10 PER CENT BENTONITE MIXTURE AFTER HEATING TO VARIOUS TEMPERATURES.

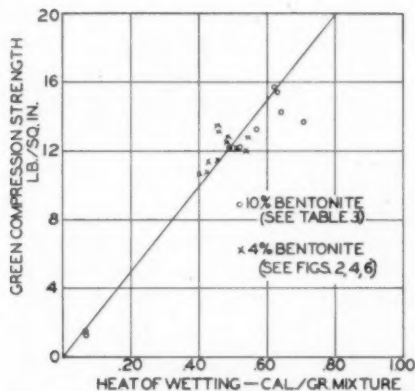


FIG. 9—RELATIONSHIP OF GREEN COMPRESSIVE STRENGTH TO HEAT OF WETTING OF HEATED 10 PER CENT BENTONITE MIXTURES.

39. A fact which should not be overlooked is that the effectiveness of a bond agent may be decreased as the percentage of bond substance is increased. In other words, the most efficient distribution of the bond material around the sand grains is, in the present case, with less than 10 per cent bentonite. The maximum green strength per unit of bentonite is probably in the lower range of from 2 to 4 per cent of the bonding clay. Thus, the original sample containing 10 per cent bentonite does not develop maximum effectiveness of the bond substance, but the heated samples, with a resulting decrease in the amount of active bond, may develop more nearly full use of the available bonding material.

40. Although data and curves on heat of wetting and strength relationships are offered, the writer recognizes that the seemingly evident conclusion that heat of wetting is an index of bonding strength should not be too quickly drawn.

#### *Influence of Total Surface Area*

41. For example, Table 4 shows sieve analysis data for the sand used during the previously described heating tests. Unfortunately, fineness distribution of the clay substance (A. F. A.) is not available. It is evident, nevertheless, that there is a radical change in size distribution. Without question, heat of wetting (and any other characteristic dependent upon surface) should vary simply as a function of the surface area. Therefore, total surface area changes may be reflected in the heat of wetting and strength curves.

Table 4

| Sieve<br>Size | Percentage retained on Sieve after<br>Heated to Temperature Noted |         |         |          |          |
|---------------|---|---------|---------|----------|----------|
|               | Original  | 600° F. | 800° F. | 1000° F. | 1400° F. |
| 40            | ...   | 0.38    | ...     | ...      | 1.08     |
| 50            | 0.08  | 0.58    | 0.09    | ...      | 4.18     |
| 70            | 0.58  | 2.58    | 0.52    | 0.98     | 10.78    |
| 100           | 25.82   | 30.38   | 28.38   | 30.78    | 48.18    |
| 140           | 44.38   | 39.78   | 41.58   | 38.98    | 26.98    |
| 200           | 13.06   | 11.18   | 12.18   | 12.78    | 4.18     |
| 270           | 2.22  | 1.58    | 1.98    | 2.08     | 2.08     |
| Pan           | 3.62  | 1.34    | 2.58    | 2.88     | 1.86     |
| A.F.A. Clay   | 10.32   | 10.94   | 9.10    | 10.22    | 2.82     |

42. Thus, while similar trends in the change of heat of wetting and bond strength may be observed, the proportionate change, due directly to change in total surface, is unknown. Conversely, while a change in the bond substance may be recognized as a result of heat application, the direct correlation of the heat of wetting may be masked partially by the simultaneous change of total surface area.

43. It is therefore fortunate that a simple mixture of sand and bentonite was used. It is apparent from the data of Table 4 that the effect of heat on the clay substance was not great, even at temperatures as high as 100° F. Furthermore, heating to 1400° F. had the effect of greatly reducing the amount of clay substance. While a decrease in particle size may have also occurred, the radical reduction in total clay substance weight would easily counteract any increase in area due to particle size decrease. This point will be discussed again in a later paragraph.

44. Therefore, Fig. 9 might be interpreted as showing maximum possible, rather than actually developed, strengths as a function of the heat of wetting. If this thought be correct, data secured on 4 per cent bentonite mixtures (which percentage is near to that where most effectiveness of the available bond will be secured) should fit the curve drawn. This is actually the case. Information given by Fig. 2 and Curve B, Fig. 6, for 4 per cent bentonites with 1 per cent temper moisture, has been plotted in Fig. 9 by small crosses. It will be noted that this data fits very well the curve already drawn.

45. The general relationship between maximum possible bond strength and heat of wetting therefore, is suggested as: Equation

(2)—Bond Strength (lb. per sq. in. A. F. A.) =  $25 \times$  Heat of Wetting (calories per gram of mixture.)

#### EFFECT OF HEAT ON CHARACTERISTICS OF NATURAL MOLDING SANDS

46. A series of natural molding sands also were studied. Samples of these sands were heated to various temperatures, strength properties were measured, and heat of wetting determinations were made as before. In addition, fineness distribution curves were developed for all samples and for all conditions of heating. This fineness data was secured according to A. F. A. Standards<sup>2</sup> supplemented by hydrometer test methods. Thus, complete size descriptions for particle sizes as small as 1 micron were secured.

47. Complete specific data must, for the sake of brevity, be omitted here. Illustrations will be offered for generalized statements which are the result of analytical study of the total mass of data.

48. The smooth correlation of strength and heat of wetting characteristics, such as observed for the bentonite mixtures, were not at all evident for the natural sands. Figs. 10 through 13 are typical examples.

49. It is well known that heat application to clay minerals will result in characteristic dehydration and in alteration of physical size and shape of the particles. Changes also will occur in the silt and organic residue present in natural molding sands. These influences are all undoubtedly shown in the data secured.

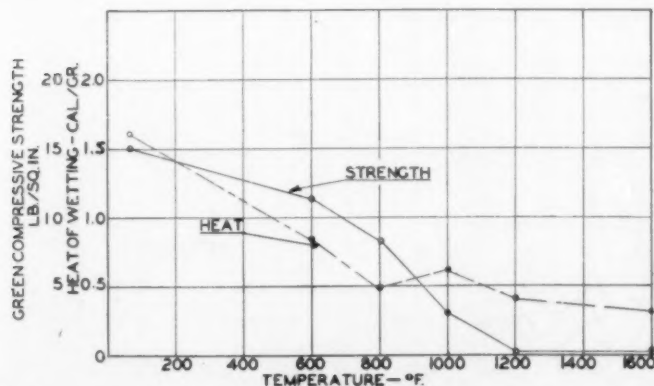


FIG. 10—RELATIONSHIP OF GREEN COMPRESSIVE STRENGTH AND HEAT OF WETTING OF HEATED NATURAL SAND "H" TO TEMPERATURE OF HEATING.

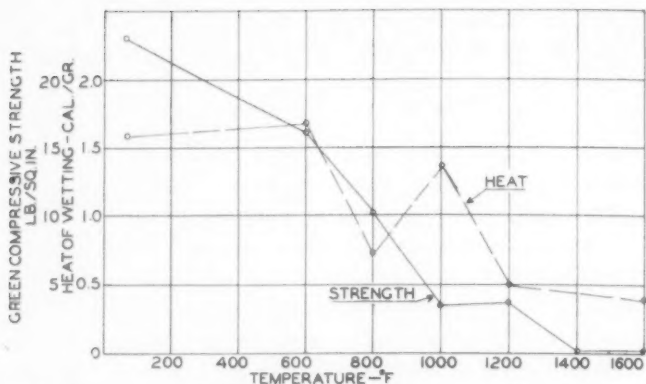


FIG. 11—RELATIONSHIP OF GREEN COMPRESSIVE STRENGTH AND HEAT OF WETTING OF NATURAL SAND "B" TO TEMPERATURE OF HEATING.

### Heats of Wetting of Natural Sands

50. The general trend of decrease of strength with increase in heating temperature was manifest for all sands tested. Heat of wetting changes varied among the different sands. For example, Sand *H*, a Tennessee sand, showed a general decrease in heat of wetting as heating temperatures were increased. A less uniform correlation was exhibited by sand *B*, a Mulberry Grove sand.

51. Sand *A*, an Albany sand, shows a much different variation of heat of wetting, especially after the sand was subjected to temperatures of 800°F. or higher.

52. A careful study of fineness distribution data offers no direct clew to the behavior of these sands. There was a regular

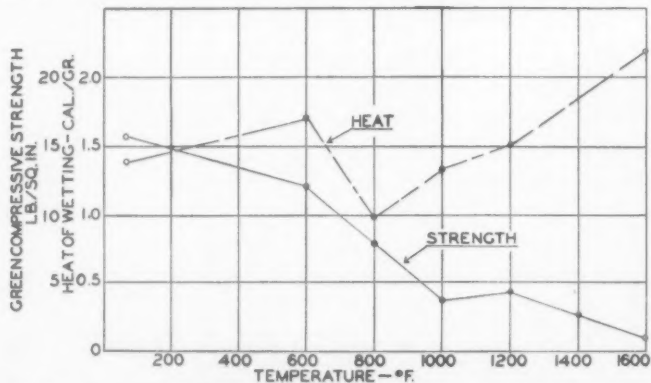


FIG. 12—RELATIONSHIP OF GREEN COMPRESSIVE STRENGTH AND HEAT OF WETTING OF NATURAL SAND "A" TO TEMPERATURE OF HEATING.

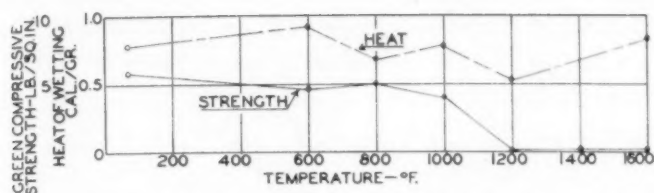


FIG. 13—RELATIONSHIP OF GREEN COMPRESSIVE STRENGTH AND HEAT OF WETTING OF NATURAL SAND "J" TO TEMPERATURE OF HEATING.

decrease (as oven heating temperature was increased) of all fines from 25 micron to 1 micron size for each of the above mentioned sands. The only statement that can be made in this connection must be in the nature of speculation. For instance, while the sub-one micron material of sand *A* decreased from 9 per cent, as received, to 2 per cent after the 1600°F. oven heating; no information as to size distribution of this 9 or 2 per cent of the total sand mixture is known. Thus, the effect of this sub-micron substance may be vital; but no direct proof is available.

53. The behavior of sand *A* was characteristic of a number of the sands studied.

54. Sand *J*, an Illinois product, shows a behavior which seems to combine some of the previously discussed variations of sands *A*, *B* and *H*.

55. The rapid increase of the heat of wetting of some sands with an accompanying decrease in strength as a result of heating, makes inapplicable the general relationship developed for bentonite

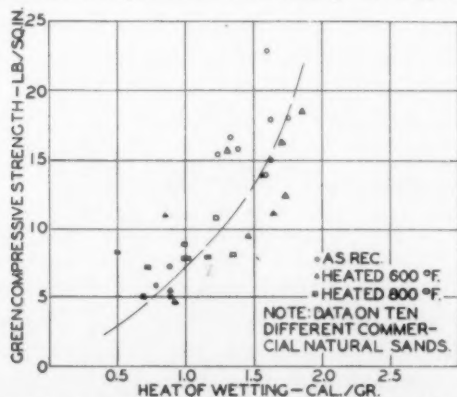


FIG. 14—RELATIONSHIP OF GREEN COMPRESSIVE STRENGTH WITH HEAT OF WETTING FOR NATURAL MOLDING SANDS AS RECEIVED AND HEATED TO LOW TEMPERATURES.

mixtures. It was felt worthwhile, however, to inspect the variation of strength as a function of heat of wetting for samples as received and for samples heated to relatively low temperatures. This has been done in Fig. 14.

56. A general, but approximate, trend is indicated. The effect of mulling water ratio was not investigated for these sands and may be an influence in disturbing the trend. Furthermore, the fact that heat of wetting may be an indication of possible rather than developed strength, may likewise be true for the natural sands.

#### BASE EXCHANGE PHENOMENA

57. Base exchange capacity has been referred to in recent literature as a criteria of clay bonding properties. Certain pertinent observations on the base exchange manifestation will therefore be offered as a basis for subsequent discussion and correlation with heat of wetting information.

##### *Definition*

58. Base exchange capacity of a clay may be defined as the ability to hold either basic or acid ions on its surface. There seems to be a great deal of disagreement upon the mechanics of the process of exchange of ions. Whether it is a process entirely at the surface or whether it is one penetrating within the space lattice; whether the reaction is chemical or purely one of physical surface adsorption are questions still not answered. That base exchange has some relationship to the clay composition is admitted but what the relationship is, has not been adequately established. Montmorillonite and beidellite are said to have generally higher exchange capacities than other clay materials.

##### *Base Exchange Capacity vs. Bond Strength*

59. The work of Grim, Bray and Bradley<sup>9</sup> and of Casberg and Schubert<sup>10</sup> have suggested that base exchange ratio is an indication of bond strength. Grim *et. al.* caution that the "—relation between these, however, is not precise, because both are influenced by particle size and bonding strength is also influenced by the identity of the exchangeable base present in clay." On the other hand, Casberg and Schubert conclude that bond strengths are

"—apparently independent of the size of the particles and the physical properties and are dependent upon the presence of the mineral or minerals carrying base-exchange capacity."

60. Both green and dry bond strengths have been discussed in terms of base exchange. The mechanics of the correlation of either or both is not entirely clear from available data.

61. More recently, Grim<sup>11</sup> has stated that the ease with which a given ion can be replaced by another is association with the hydration of the ion. He also states that the water film on the surface of the clay mineral flake results partly from the factor of base exchange. It seems further, that the cation may be held at varying distances from the flake depending upon the size and valence. Grim thus postulates an envelope of water on the surface of the flake.

62. This water film has been described as acting so as to separate the individual flakes with a resulting decrease in the effectiveness with which the flakes are held to each other.

63. Swelling and plasticity properties of clays are thus associated with a water envelope which in turn seems dependent upon several items associated with base exchange characteristics. Just how greater ionic exchange and greater ease of hydration of such ions should result at one time in not only greater plasticity due to the lubrication action of the water, but also in greater bonding or cohesive strength, has not been fully explained.

64. Nevertheless, all of the foregoing might suggest the similar influences involved in a general consideration of bond strengths, heat of wetting and base exchange.

#### SIMILAR INFLUENCES IN BASE EXCHANGE AND HEAT OF WETTING

65. Since there is a possibility that both heat of wetting and base exchange capacity are surface phenomena, it is also possible that both may be similarly influenced by the same surface conditions. There have been reports of a definite relationship between base exchange capacity and heat of wetting.

66. Pate<sup>12</sup> says, "The colloid with a high replaceable base content gave a high heat of wetting, whereas the colloid with a low replaceable base content gave a low heat of wetting." Janert<sup>13</sup> also found similar evidence and was able to show a straight line relationship between base exchange and heat of wetting; base ex-

change equalled 4.2 times the heat of wetting.

67. On the basis of Janert's work and Equation (2), page 15, the following might be written:

$$\begin{aligned}\text{Bond Strength} &= 25 \times \text{Heat of Wetting} \\ &= 25 \times 4.2 \times \text{Base Exchange}\end{aligned}$$

68. The report of Casberg and Schubert<sup>10</sup>, however, shows no such simple relationship. Figures taken from their report are shown in Table 5. It will be noted that the two natural sands show an approximate ratio of base exchange to strength and that the two synthetic mixtures have another approximate and characteristic ratio.

69. Messrs. Casberg and Schubert have offered a method of analysis of their results which takes account of inert or ineffective bond substance. This method, proposed in connection with base exchange values, suggests itself in connection with heat of wetting data.

70. Briefly, the analysis assumes bentonite as an ideal reference bonding substance. Theoretical quantity of ideal bond substance and theoretical strength are calculated on the basis of base exchange values. The depressing effect on strength by the non-ideal bond substance is thus determined and should be of a constant value. Further details of the method may be found in the reference noted.

Table 5

BASE EXCHANGE CAPACITY AND GREEN STRENGTH DATA TAKEN FROM REPORT OF CASBERG AND SCHUBERT

| <i>Sand</i>           | <i>Base<br/>Exchange<br/>Capacity</i> | <i>Green<br/>Strength,<br/>lb. per sq. in.</i> | <i>Ratio</i> |
|-----------------------|---------------------------------------|--|--------------|
| Mulberry Grove.....   | 7.7                                   | 16.0   | 2.08         |
| Albany .....          | 2.9                                   | 7.1  | 2.45         |
| Normal Bentonite..... | 3.77                                  | 4.0  | 1.09         |
| Normal Ohio Clay..... | 4.75                                  | 4.3  | 0.93         |

*Evaluating Effect of Non-Ideal Bond Substance*

71. This same method has been adapted to the present heat of wetting data. Table 6 shows values. Although the outline of the table is identical with that of Casberg and Schubert's work, the following brief notes are offered as an aid in following the calculations involved.

Table 6

STRENGTH ANALYSIS OF NATURAL MOLDING SANDS BASED ON  
HEAT OF WETTING

| Sand         | Bond<br>—25 $\pi$<br>per<br>cent | Heat of<br>Wetting,<br>Cal. per<br>gr. | Actual<br>Green<br>Strength,<br>lb. per<br>sq. in. | Bent.<br>Equiv-<br>alent<br>per<br>cent | Non-<br>Bent.<br>Equiv-<br>alent,<br>per<br>cent | Calc.<br>Ideal<br>Strength,<br>lb. per<br>sq. in. | Diff.<br>in<br>Strength | Depressing<br>Effect,<br>lb. per sq.<br>in. per gr.<br>non-benton-<br>ite |
|--------------|----------------------------------|--|--|---|--|---|-------------------------|---|
| A            | 28.0                             | 1.38                                   | 15.7   | 10.6                                    | 17.4   | 34.6  | 18.9                    | 1.09  |
| B            | 22.0                             | 1.59                                   | 23.0   | 12.2                                    | 9.8  | 39.8  | 16.8                    | 1.72  |
| C            | 24.0                             | 1.32                                   | 16.6   | 10.1                                    | 13.9   | 33.0  | 16.4                    | 1.18  |
| D            | 19.0                             | 1.23                                   | 15.5   | 9.5                                     | 9.5  | 30.8  | 15.3                    | 1.61  |
| E            | 14.0                             | 0.87                                   | 7.2  | 6.7                                     | 7.3  | 21.7  | 14.5                    | 1.98  |
| F            | 35.3                             | 1.58                                   | 14.0   | 12.1                                    | 23.2   | 39.6  | 25.6                    | 1.11  |
| G            | 22.0                             | 1.74                                   | 18.0   | 13.4                                    | 8.6  | 43.5  | 25.5                    | 2.96  |
| Bent.        | 100.0                            | 13.00                                  | ...  | 100.0                                   | 0.0  | ...   | ...                     | ...   |
| Average 1.66 |                                  |  |  |   |  |   |                         |   |

72. *Col. 2*—The per cent of bond substance for purposes of this study was arbitrarily taken as —25 $\pi$  substance. The complete size distribution curved down to 1 $\pi$  was available and values were taken from curves drawn from the data.

73. *Col. 3*—The heat of wetting values were secured as previously described.

74. *Col. 4*—Green strength values are at optimum temper moisture quantities for each sand.

75. *Col. 5*—Bentonite equivalent equals Heat of Wetting per 13 cal. per gram as per Equation (1), page 10.

76. *Col. 6*—Non-bentonite equivalent equals total actual bond substance minus bentonite equivalent, or *Col. 3* minus *Col. 5*.

77. *Col. 7*—The calculated ideal strength equals 25  $\times$  (Heat of Wetting) as per Equation (2), page 15.

78. *Col. 8*—Difference between the calculated and actual green strengths or *Col. 8* minus *Col. 4*.

79. *Col. 9*—Depressing effect of Non-bentonite equals *Col. 8* divided by *Col. 6*.

80. If the results for sample *G* are excepted, a fair degree of uniformity is shown for the depressing effect on the green strength per gram of the so-called non-bentonite equivalent.

81. Table 6 refers to natural sands as received. Similar calculations have been made for oven heated samples. Figures given in Table 7 correspond to those of the final column of Table 6.

Table 7

RESULTS OF STRENGTH ANALYSIS OF HEATED NATURAL SANDS  
BASED ON HEAT OF WETTING

| Sand | <i>Depressing Effect on Green Strength—<br/>lb. per sq. in. per gram Non-Bentonite</i> |                              |
|------|--|------------------------------|
|      | <i>Heated to<br/>600° F.</i>   | <i>Heated to<br/>800° F.</i> |
| A    | 3.58   | Negative                     |
| B    | 3.36   | 5.50                         |
| C    | 5.21   | 2.99                         |
| D    | 2.96   | 6.70                         |
| E    | 1.42   | 2.21                         |
| F    | 1.50   | 1.68                         |
| G    | 3.74   | 16.90                        |

82. The calculated depressing effect on the green strength by unit weight of the so-called non-bentonite equivalent for natural sands heated to 600 and 800°F. is not constant. Whereas the method proposed for analysis on base exchange data may be applied with fairly satisfactory results to heat of wetting information on as received natural sands, the correlation is lost when the method is applied to heated sands.

83. Radical changes occur in size distribution during heating. After making many fineness distribution tests of heated molding sands and after careful study of trends and results, the writer is convinced that the method of analysis outlined, and as originally proposed for base exchange properties, will show a lack of correlation when applied to the base exchange phenomena of heated samples just as it has been shown here to not be applicable to the heat of wetting data of heated samples.

84. It should be remarked here that the method, whether applied to base exchange or heat of wetting, is dependent upon a decision on the size of fines which should be classified as bond substance. The dividing line, whether it be 5, 20 or 25 micron becomes, at least for the present, arbitrary. A great variety of results may be obtained depending upon the size limit set up for purposes of the calculation. This is a vital factor, and in fact becomes the controlling item, when any attempt is made to generalize the method.

## APPLICATION OF HEAT OF WETTING CHARACTERISTICS

85. Since the unknown factors which influence the strength of a natural molding sand make inadvisable a rigorous mathematical application of the heat of wetting theory developed for bentonite-sand mixtures, only a general statement of bonding efficiency of natural sand mixtures should be made at this time in terms of the heat of wetting. Reference to Table 8 will illustrate the thought.

Table 8

## EFFECTIVENESS OF NATURAL MOLDING SAND BOND SUBSTANCE

| <i>Sand</i>       | <i>Calculated<br/>Strength,<br/>lb. per<br/>sq. in.</i> | <i>Actual<br/>Strength,<br/>lb. per<br/>sq. in.</i> | <i>Per Cent<br/>Effective-<br/>ness<br/>of Bond</i> |
|-------------------|---|---|---|
| "A" As Received   | 34.6  | 15.7  | 45.3  |
| Heated to 600° F. | 43.0  | 12.1  | 28.1  |
| 800               | 24.5  | 7.7   | 31.4  |
| 1000              | 33.8  | 3.7   | 11.0  |
| 1200              | 37.8  | 4.3   | 11.4  |
| 1600              | 54.8  | 1.0   | 1.8   |
| "B" As Received   | 39.8  | 15.7  | 57.9  |
| Heated to 600° F. | 42.3  | 16.3  | 38.6  |
| 800               | 18.5  | 7.1   | 38.4  |
| 1000              | 34.3  | 3.5   | 10.4  |
| 1200              | 12.5  | 3.7   | 29.6  |
| 1600              | 9.8   | 0.0   | 0.0   |

86. The figures shown for "Calculated Strength" are secured on the basis of Equation (2)—Calculated strength =  $25 \times$  (Heat of Wetting per gram.) The figures noted as "Actual Strength" are green strengths determined according to A. F. A. Standards<sup>2</sup>. The ratio of the actual strength to the calculated strength becomes an index of bond substance efficiency. This ratio, stated as a percentage, makes the maximum strength which might be expected from an ideal bentonite mixture as the 100 per cent base.

87. It is apparent that this method of examination makes no assumption on the size of the material to be classed as bond substance. Rather, the entire sand mixture is treated as a unit. Large particles contribute little to heat of wetting and, so far as is known, apparently contribute little to strength. Small and colloid size particles which are difficult to examine or test are paramount in this scheme. Inert fines may be contributing to

lower the efficiency percentage calculated. Additional investigation is required on this point.

88. The present A.F.A. Standards<sup>2</sup> yield data on the quantity of minus 20 micron material which is defined as A. F. A. clay substance. Size and analysis information of this fraction can be secured but the processes are tedious and expensive if applied to the very fine one micron or smaller material. The method noted in paragraph 86, provides a simple procedure of investigating the effectiveness of the A.F.A. clay substance. No advance has been made, of course, in specifically separating for identification, test or discussion that material in natural molding sands which positively contributes to the bond strength.

89. A similar, though somewhat more general application of these facts, seems reasonable for bentonite mixtures. Table 9 illustrates the theory of correlation of heat of wetting to strength by the use of specific figures which are taken from typical cases from previously discussed data.

90. For bentonite mixtures, two calculated strengths are possible: (A) Based on ultimate heat of wetting of the bentonite content as per Equation (1) and (2), and (B) based on actual heat of wetting of the bentonite mixture and Equation (2). Columns 1 and 2 of Table 9 are in accord with these two methods. In review of what has been said in earlier paragraphs, a comparison of these two columns gives an indication of the effectiveness of the mixing of the sand and bentonite.

91. Cases 3 and 5 show appreciable differences in these two values. Such differences has been ascribed to low water-clay ratios during mulling.

92. Comparison of the actual test strength with values of column 2 is the same as already outlined for natural sands, and the ratio stated as a percentage therefore evaluates the efficiency of the bonding clay. Since the unknowns, such as are present in natural sands, are not here involved; more specific statements are possible.

93. Case 1 is obviously at optimum conditions. Case 2, while properly mixed and mulled, shows a 58.5 per cent efficiency because of improper temper moisture. Case 3, already noted as inadequately mulled, shows a 98 per cent efficiency of the bond insofar as the mulling condition permits.

Table 9

## EFFECTIVENESS OF BOND IN BENTONITE SAND MIXTURES

| Case<br>Description  | Calculated Strength,<br>lb. per sq. in.  |   | Test<br>Strength,<br>lb. per sq. in. | Ratio.<br>Test<br>Strength to<br>Calculated<br>Strength<br>per Col. 2<br>Per Cent<br>Effective-<br>ness of<br>Bond |
|--|--|---|--------------------------------------|--|
|  | Column 1<br>Based on<br>bentonite<br>per cent<br>and Equa-<br>tions<br>1 and 2 | Column 2<br>Based on<br>Actual<br>Heat Wet-<br>ting and<br>Equation 2 |                                      |  |
| 1. 4 per cent Bentonite-<br>Mulling Ratio equals<br>1 - Temper Moisture<br>1 per cent    | 13.0   | 12.2<br>13.5<br>Avg. 12.8   | 13.1                                 | 102.2  |
| 2. 4 per cent Bentonite-<br>Mulling Ratio equals<br>1 - Temper Moisture<br>4 per cent    | 13.0   | 12.8  | 7.5                                  | 58.5   |
| 3. 4 per cent Bentonite-<br>Mulling Ratio equals<br>¼ - Temper Moisture<br>1 per cent    | 13.0   | 10.6<br>10.0<br>Avg. 10.3   | 10.1                                 | 98.0   |
| 4. 8 per cent Bentonite-<br>Mulling Ratio equals<br>1 - Temper Moisture<br>2 per cent    | 26.0   | 23.8<br>27.8<br>Avg. 25.8   | 16.9                                 | 65.5   |
| 5. 10 per cent Bentonite-<br>Mulling Ratio equals<br>0.2 - Temper Moisture<br>6 per cent | 32.5   | 17.4  | 13.6                                 | 78.1   |
| 6. 16 per cent Bentonite<br>1000° F. Heating   |  | 12.2<br>13.0<br>Avg. 12.6   | 12.2                                 | 96.5   |

94. Case 4 illustrates the use of excessive bond and the lack of opportunity for each portion of the bond to effectively develop strength. Case 5 has been shown to have poor mulling water ratio and in addition is similar to case 4 with respect to ineffectiveness of the large percentage of bentonite.

95. Case 6, being heated after the mulling, shows good efficiency of the bond still undamaged by the heating.

## CONCLUSIONS

96. It is only reasonable to recognize that the composition and physical condition of the clay bond should be important elements in determining the effectiveness of that bond substance. It has been frequently noted in the literature that clay particle size is important. The general statement is satisfactory, but evidence

on specific cases is not conclusive and many statements must still be considered as speculative. The problem of separating, positively identifying fractions and finally assigning final mixture characteristics is still a fertile field for investigation.

97. Paramount in the proper pro-rating of individual component characteristics to the composite mixture of molding sand is the fact that the physical combination factors may be as important as any other item. The practical manipulation of a foundry sand must not be overlooked in arriving at final conclusions and evaluations of sand bonding materials.

98. The scientific investigation of the constitution, size and physical-chemical characteristics of bonding clays is all important in arriving at the fundamental facts. The writer simply cautions on the generalization of these individual details which may be masked in the actual combinations of molding sands.

99. Accordingly, no dogmatic statements regarding the special phenomena here discussed are intended. Rather, a basis for discussion which may prove of help in the pursuit of truths in the foundry molding art are offered:

1. There is an optimum (strength basis) mulling water to bentonite ratio for sand-bentonite mixtures.

2. Heat of wetting of sand-bentonite mixtures is influenced by mulling practice.

3. Optimum mulling water and maximum heat of wetting occur at mulling water to bentonite ratios of about 1.

4. Heated bentonite-sand mixtures have shown a correlation of strength and heat of wetting.

5. The maximum heat of wetting of bentonite has been found to equal 13 calories per gram of bentonite.

6. The general relationship for maximum, limiting strengths for bentonite mixtures is given:

Strength, lb. per sq. in. A. F. A. =  $25 \times$  (heat of wetting, cal. per gram of mixture.)

7. Approximate correlation of strengths with heat of wetting has been found for natural sands as received.

8. The effect of heat on natural sands, especially when viewed on the basis of fineness distribution, makes the rigorous mathematical theory developed inadvisable for natural sands.

9. Influences similar to those noted in (8) are possibly active in base exchange theories and the general application of such theories to all molding sand mixtures is similarly questioned.

10. A method of inspection of bond substance efficiency has been offered.

#### ACKNOWLEDGMENTS

100. The detailed laboratory work was performed primarily by Robert S. Sherwood. The writer wishes to acknowledge the helpful suggestions of many of his past colleagues at the Iowa State College. The work here reported is correlary to the investigation of Iowa natural molding sands; the program being sponsored by the Iowa Engineering Experiment Station, of which Dean T. R. Agg is director.

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## DISCUSSION

*In the absence of the author this paper was presented by Prof. R. S. Sherwood, Dept. of Mechanical Engineering, Iowa State College, Ames, Ia.*

*Presiding:* W. G. REICHERT, American Brake Shoe & Foundry Co., Mahwah, N. J.

R. E. GRIM:<sup>1</sup> The author made one comment that I agree with very heartily, and that is considerable caution must be used in generalizing on the results obtained in a study of one synthetic sand using just one type of clay. There is little doubt of the fact that if similar studies were made using other types of clay, perhaps using even another kind of bentonite, somewhat different results might follow. At present, it is a rather generally accepted concept that clays are essentially composed of extremely minute flakes of crystalline minerals, and the different clays are composed of different minerals. One of the outstanding attributes of the different clay minerals that make up clays is the difference in the ease with which they tend to break down when they are worked, that is, the difference in the ease with which the particles break down into smaller flakes when they are mulled, for example. So, it would seem from that, if another kind of clay or another kind of bentonite were used, the results might vary somewhat.

Just a word with regard to this subject of base exchange. There are two factors that must be taken into account. One is the base exchange capacity of the clay, and the second is the character of exchangeable base that the clay carries. For example, if two bentonites are found to have the same base exchange capacity, but one carried hydrogen as the exchangeable ion and the other carried sodium, there is little doubt that the physical properties of the two bentonites would not be the same. Thus, it is necessary to consider not only the base exchange capacity but also the character of the exchangeable base carried by the clay.

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## Melting of Copper-Base Alloys to Retain Physical Properties

BY W. B. GEORGE\*, CHICAGO, ILL.

### Abstract

*Over the many years that the writer has been engaged in the investigation and correction of foundry difficulties in the non-ferrous field, the problems have been many and varied. However, the problem which seems of outstanding importance is that of meeting physical property requirements. While many foundries have mastered general problems, others search in the dark for solutions to their difficulties, and it is to these that the author directs this paper. Although it is impossible to lay down a universal cure-all for the difficulties encountered in meeting physical property specifications, it is the writer's intention to outline the practice that is being used most universally to obtain satisfactory results. Some plants may have achieved more advanced methods than those recommended, and the author asks that such bear with him in his efforts to assist others in the non-ferrous foundry industry. Any such better working methods will be welcome, even though they be only for a single alloy.*

1. Physical properties are "built" into the different alloys from which castings are made by compounding various metals to meet specific requirements. After an alloy is compounded to meet certain physical requirements, it often is discouraging to find that the intended properties are lowered to such an extent in the foundry manipulation, that the castings have to be rejected. Such losses in properties can be attributed to two causes: (1) Lack of feeding and (2) gas absorption. Either of them is easily detected by a fracture of the specimen.

\* R. Lavin & Sons.

NOTE: This paper was presented at a Non-Ferrous Session of the 44th A.F.A. Convention, May 7, 1940, Chicago, Ill.

2. If lack of feeding is a cause, the metal will show a localized discoloration in the fracture with a clear outline of crystalline structure. When the fracture shows an even distribution of small holes, with larger ones outcropping in the heavier sections, and an absence of outlined crystals, the metal is definitely gassed. In mild cases of either, where the eye cannot differentiate, a magnifying glass will clear the doubt.

3. As feeding is well understood by foundrymen, only absorption will be discussed.

#### *Causes of Gas Absorption*

4. Gas is absorbed by the bath of metal in the furnace from a reducing atmosphere and is liberated within the casting in inverse proportion to its solidification rate. There is no cure-all for this gassed metal condition regardless of the type of furnace used. Gas, oil, coke or indirect-arc electric furnaces all will produce gassed metal, if not properly operated. This gas absorption is governed by three invisible dimensions; temperature, furnace atmosphere and time.

5. Means for measuring these three dimensions are not as simple as the length, breadth and depth used by the rest of the plant. Due to this fact, melting is least understood and, when properties fail, the blame is passed back and forth until it often reaches the supplier of raw materials. Numerous foundries refuse to take on work demanding that physical properties be met and openly admit it is beyond their control to do so.

#### MELTING UNITS FOR COPPER-BASE ALLOYS

6. There are many mediums employed in melting copper-base alloys. Practice varies from plant to plant. The author will endeavor to include the mediums with which he is familiar and will designate the best general procedure for melting, with each type.

7. The equipment to which these recommendations apply is grouped, for simplicity of explanation, and consists of the following types:

- Oil fired crucible furnace
- Gas fired crucible furnace

- Oil fired open flame furnace
- Gas fired open flame furnace
- Coke fired crucible natural draft
- Coke fired crucible blast draft
- Electric, indirect-arc

Before a thorough understanding of this subject can be achieved, it will be necessary for each foundry to make a study of its particular set-up.

#### GENERAL MELTING PRACTICE

8. In an efficiently operating furnace, metal has a liberal leeway and some shops function without even such essential equipment as pyrometers. In many of these cases, it is more good fortune than knowledge when production results are satisfactory, for somewhere along the line, a good furnace designer was involved.

9. However, all equipment does not possess these redeeming features, and it is necessary to plot charts to determine just where the weakness lies. The writer has used a graphic method to chart the operation of existing equipment and has been able to clear up gas conditions by either a revamping of the equipment or by establishing a stabilized melting practice. Where furnace help has not been fully competent, at times, it has been necessary to insist upon both.

10. Fig. 1 illustrates the method as it applied to an installation of No. 80 oil-fired crucible furnaces, melting 85-5-5-5 brass alloy. The dotted line shows the limit control that was used to keep gassed metal from being poured into the castings. The tensile strength and gas pickup have a direct relation to each other and the dotted line in Fig. 1 can be established by fractures.

11. Data for such a chart are compiled by taking the most difficult alloy (in most shops it is the 88-10-2) and pouring test bars from a single melt, casting them from low to high temperatures; and keeping track of time, temperature and atmosphere. As the reducing side is where gas pickup is obtained, the melting zone must be kept reducing during the test. However, in actual practice, an oxidizing atmosphere can be used, with a far wider range of insurance.

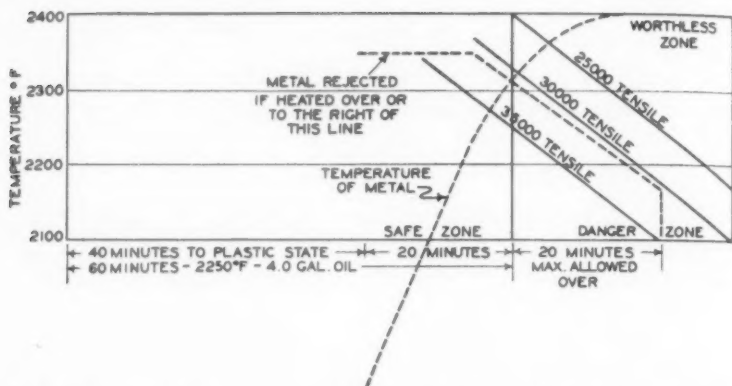


FIG. 1—PERFORMANCE CHART FOR NO. 80 CRUCIBLE OIL-FIRED FURNACE MELTING 85-5-5 RED BRASS.

#### *Method of Determining Condition of Furnace Atmosphere*

12. It is easy to tell whether an atmosphere is reducing or oxidizing by the following methods:

(1) On oil or gas-fired equipment, pass a piece of zinc through the flame and should it come out black, a highly reducing condition exists. If the zinc shows straw yellow to light gray, the atmosphere is slightly reducing and if the zinc remains as clear as when inserted, it is oxidizing.

(2) On coke pit furnaces, if the crucible top sets below the flue opening, it is safe to assume that the atmosphere over the metal is reducing. This can be further checked by skimming back the charcoal and noting whether or not an oxide film follows the skimmer. If it does so, the atmosphere over the metal is oxidizing.

(3) On electric (indirect-arc) furnaces, if the electrodes burn nearly square, the atmosphere in the furnace is ideal to reducing. When excess oxygen exists, the electrodes burn into long tapers with a heavier electrode consumption. A little practice in checking this point will enable the melter to do a much better job.

#### *Fuel Consumption*

13. Good melting practice will consume the amounts of fuel or current for each 100 lb. of metal melted, after the furnace is once hot, as shown in Table 1. This does not mean that good metal will

Table 1

## FUEL CONSUMPTION PER 100 LB. OF METAL MELTED

| Type Furnace             | Fuel        | Consumption    |
|--------------------------|-------------|----------------|
| Stationary Crucible..... | { Oil       | 2 gal.         |
|                          | { Gas       | 320,000 B.t.u. |
| Tilting Crucible.....    | { Oil       | 1.6 gal        |
|                          | { Gas       | 300,000 B.t.u. |
| Open Flame.....          | { Oil       | 1.4 gal.       |
|                          | { Gas       | 280,000 B.t.u. |
| Pit, Natural Blast.....  | Coke        | 25 lb.         |
| Indirect-Arc.....        | Electricity | 15 kwh.        |

not be obtained if additional fuel is used. However, the equipment most likely will bear checking, as this may indicate a potential source of trouble.

14. It should be noted that, where charges are less than 200 lb., no figures of economy have been established.

*Melting Time*

15. A universal standard of good melting time is given in Table 2.

Table 2

## MELTING TIMES FOR VARIOUS TYPE FURNACES

| Type Furnace           | Fuel         | Charge, lb. | Proper Melting Time, Min.    |
|------------------------|--------------|-------------|------------------------------|
| No. 80 Crucible        | { Oil or gas | { 240       | 60 or less                   |
| No. 70 Crucible        |              | { 210       | 50 or less                   |
| No. 60 Crucible        |              | { 180       | 40 or less                   |
| Open Flame             | Oil or gas   | { 1000      | 60 or less                   |
|                        |              | { 2000      | 90 or less                   |
| Pit                    | Coke         | All Sizes   | { 60 to 90 (Blast)           |
|                        |              |             | { 120 to 180 (Natural Draft) |
| Electric, Indirect-arc | Electricity  | { 300       | 20                           |
|                        |              | { 500       | 30                           |

16. In a good oil or gas-fired furnace, it requires two-thirds of the total time to bring the metal to the full plastic state and the remaining one-third to raise it to the pouring stage. In crucible equipment, the maximum temperature of the furnace side wall must be 2800°F. to maintain the ratio. On open flame furnaces, 2600°F. is sufficient.

17. Where the maximum temperature of furnace side wall is low, the ratios drop considerably, with a loss of fuel and poorer metal.

18. While the writer would like to discuss furnace design, he feels that the information given will be sufficient for a checkup, and the foundryman can call in his equipment builder to make the necessary corrections if desired.

#### DEOXIDIZERS

19. On red brasses and tin bronzes, phosphorus often is added both to oxidized and gassed metals to reduce the metal back to the neutral zone. Phosphorus has a two-fold effect: first, it reduces oxides and second, should the metal be gassed, there is, to some extent, a liberation of the absorbed gas content. Other deoxidizers and degasifiers are made for this same purpose. Some leave a residual balance which is harmful.

20. To cover this subject of deoxidation and degasification further would be leading the reader to believe that he could cure his troubles in this manner. However, such is not always the case. Fig. 2 illustrates the reaction of phosphorus in either an oxidized or reduced bath of metal.

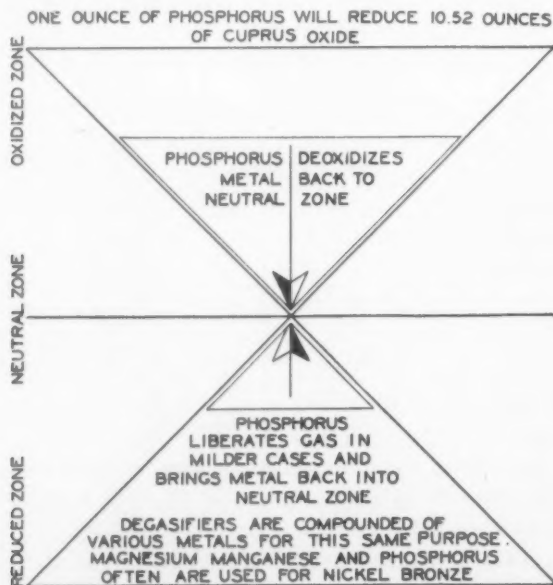


FIG. 2—GRAPHIC REPRESENTATION OF THE RELATIVE EFFECT OF PHOSPHORUS IN OXIDIZED AND REDUCED METAL.

**Table 3**

DEOXIDIZERS AND THE RELATIVE AMOUNTS OF OXYGEN THEY WILL ELIMINATE

| <i>Deoxidation by the<br/>Following Element</i> | <i>Will Eliminate</i> | <i>The Following Oz.<br/>of Oxygen</i> |
|---|-----------------------|--|
| Boron .....                                     |                       | 2.21                                   |
| Phosphorus .....                                |                       | 1.29                                   |
| Silicon .....                                   |                       | 1.14                                   |
| Aluminum .....                                  |                       | 0.889                                  |
| Magnesium .....                                 |                       | 0.658                                  |
| Calcium .....                                   |                       | 0.400                                  |
| Manganese .....                                 |                       | 0.291                                  |
| Zinc .....                                      |                       | 0.243                                  |

21. In addition to phosphorus, the elements shown in Table 3 can be used as deoxidizers in various alloys.

22. The effectiveness of deoxidizers is best just before pulling the heat. Each has value and is generally alloyed in various proportions and sold on analysis, or in compounds, to accomplish certain results.

23. There is no set amount of phosphorus or other elements that should be used. The amount can only be determined by final analysis of the casting and the residual amounts of the various elements that are permissible.

24. Table 4 lists some popular alloys and the amount of 15

**Table 4**

AMOUNTS OF 15 PER CENT PHOSPHOR-COPPER USED TO DEOXIDIZE VARIOUS COPPER-BASE ALLOYS

| <i>Copper,<br/>per cent</i> | <i>Alloys Melted</i>     |                           |                           | <i>Amount of<br/>15 per cent<br/>Phosphor-Copper<br/>Added,<br/>oz.</i> |
|-----------------------------|--------------------------|---------------------------|---------------------------|---|
|                             | <i>Tin,<br/>per cent</i> | <i>Lead,<br/>per cent</i> | <i>Zinc,<br/>per cent</i> |   |
| 90                          | 10                       | 0                         | 0                         | 4   |
| 88                          | 10                       | 0                         | 2                         | 2   |
| 88                          | 8                        | 0                         | 4                         | 1½  |
| 85                          | 5                        | 5                         | 5                         | 1½  |
| 81                          | 3                        | 6                         | 10                        | 1   |
| 80                          | 10                       | 10                        | 0                         | 4   |

per cent phosphor-copper that is being used per each 100 lb. of metal.

#### CHECKING METAL FOR GAS

25. After the alloy is melted and brought up to desired casting temperature, it will be found to be either oxidized or gassed, in proportion to the length of time it remained in the particular atmosphere in the furnace. The alloy can be checked for gas pick-up before pouring into the mold.

26. To do so, punch a  $1\frac{1}{2}$ -in. diameter sprue cutter into the corner of a mold and pour the cavity  $\frac{1}{2}$ -in. short of the top. Scrutinize carefully for a few seconds to note the manner in which the metal sets. If a good shrink sets in, the metal is satisfactory. However, if the test piece bulges on the top, it is gassed. Should strings form on the pouring lip and black specks rise to the surface of the bath, the metal is highly oxidized.

27. While it is conceded that an oxidizing atmosphere is desirable, most plants melt under slightly reducing atmospheres, since metal losses are lessened, burners are more easily adjusted, and melting is rapid. An oxidizing atmosphere is hard to maintain with any degree of accuracy by manual control.

#### MELTING PROCEDURES FOR VARIOUS TYPES OF FURNACES

28. Following is outlined the different phases of melting procedure for the equipment mentioned.

##### *Compounding Alloys*

29. If a foundry mixes its own alloys, these recommendations should be incorporated in its practice. Heat the copper to its plastic state, then add zinc, lead and tin in the order mentioned. When copper and tin only are used; melt the copper first, then add 2 oz. of 15 per cent phosphor-copper shot per each 100 lb. of melt 5 min. before the tin is added. This prevents the tin from oxidizing.

30. In making nickel bronze, melt the copper and nickel together, as they will go into solution and need not heat up to the melting point of nickel.

##### *Natural Draft and Blast Coke-Fired Furnaces*

31. Heat the crucible in the furnace until red hot. Use enough coarse charcoal, which will reduce oxides, to cover the bottom. Then

charge ingot or heavy material and continue charging into crucible until it is filled, never allowing the alloy to get above the plastic stage. Then superheat to pouring temperature.

32. Do not heat the metal more than 100°F. above the temperature at which the metal is to be poured and do not hold the melt in the furnace after it reaches the desired temperature.

#### *Gas and Oil-Fired Crucible Furnaces*

33. Heat the crucible until red hot. Then place 1/2-lb. of glass per 100 lb. of metal on the bottom to create slag. Slag of this type will pick up oxides as well as cover the metal.

34. Weigh out the total charge to be melted and place as much in the crucible as possible. The remainder should be placed on top of the furnace to be pre-heated, and charged into the crucible as fast as the pot will receive it.

35. Do not let the metal get above the plastic range at any time until the crucible is filled, and then superheat for pouring.

36. It will be necessary to skim the slag from the top of the melt when the crucible is pulled, before adding any deoxidizer.

37. Do not heat the alloy more than 100°F. above the temperature at which the metal is to be cast; or let it stand or soak in the furnace once this temperature has been reached. Metal cannot be heated to a high temperature, then cooled down, as some of the gas absorbed in melting still will be entrapped and remain in the casting.

#### *Electric, Indirect-Arc Furnaces*

38. Preheat the lining until red hot before charging. Do not heat the metal more than 100°F. above the temperature needed to cast it, and do not hold the metal in the furnace until it is necessary to reheat it if sound work is to be expected.

39. The pouring hole of the furnace must be kept at the proper size to avoid excessive electrode consumption.

40. The alloy must be tapped from the furnace when the proper temperature is reached. Care must be exercised in charging gates over the electrodes, for the sand that comes into the zone of the arc will be reduced to silicon.

*Open-Flame Furnaces Where Products of Combustion  
Come in Direct Contact with the Metal*

41. Heat the furnace until red hot, then put in  $\frac{1}{2}$ -lb. of glass for each 100 lb. of metal to be charged. Place the entire charge, if possible, within the furnace and melt.

42. If the entire heat cannot be charged at once, do not bring the bath in the furnace above the plastic range until the entire charge is in the furnace.

43. Do not heat the metal over  $100^{\circ}\text{F.}$  above the temperature at which it is to be poured and do not hold the alloy in the furnace after it is ready.

TEST RESULTS OF PRACTICES OUTLINED

44. In order that the reader may have some comparative data, the writer ran a series of heats under the methods recommended using an oil-fired, No. 60 crucible furnace, which is representative of these used in the field. A number of alloys were selected from stock ingot of the analyses shown and their properties tabulated.

45. To eliminate all possible variables that might enter into casting test bars at different times, six identical patterns were rammed in a single mold and poured individually  $50^{\circ}\text{F.}$  apart, from the same heat of metal, as the heat rose in temperature.

46. To accomplish this, a No. 60 crucible, holding 180 lb. of metal, was used as a reservoir with a small crucible holding only 12 lb. being kept submerged in the bath and used as a dipper. The large crucible was not disturbed during the whole cycle and the small one was operated in and out of the bath with very close control.

47. It took 30 min. to reach  $2000^{\circ}\text{F.}$  and  $4\frac{1}{2}$  min. to increase the temperature each  $50^{\circ}\text{F.}$  thereafter;  $1\frac{1}{2}$  min. was consumed in pouring each bar and reading the temperature.

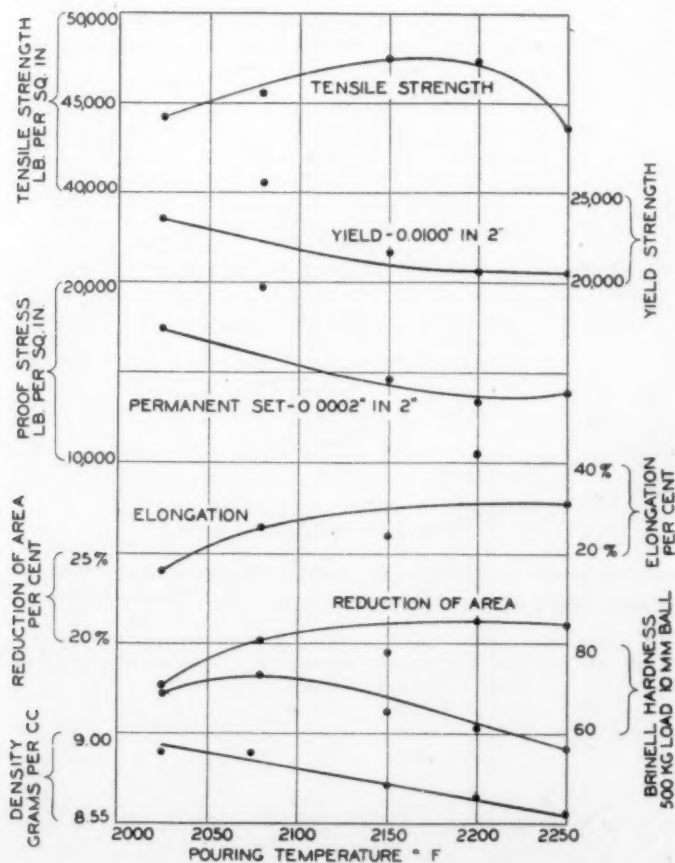
48. Sand in the mold showed a permeability of 30 and contained 6 per cent moisture.

49. Table 5 shows the amounts of 15 per cent phosphor-copper used per 100 lb. of metal just before the first bar was cast. No other additions were made to the metal cast into the bars whose results are shown in Figs. 3, 4, 5, 6, 7 and 8. On the high yield manganese bronze, no additions were made.

Table 5

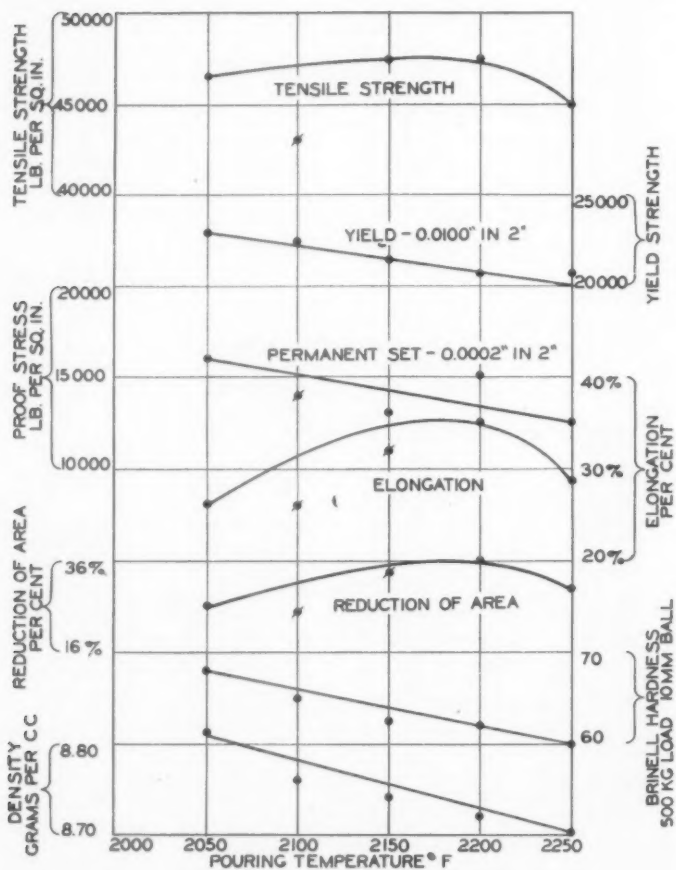
PHOSPHORUS ADDED TO VARIOUS ALLOYS USED IN INVESTIGATION

| Alloys Melted       |                  |                   |                   | 15 Per Cent Phosphor- |
|---------------------|------------------|-------------------|-------------------|-----------------------|
| Copper,<br>Per Cent | Tin,<br>Per Cent | Lead,<br>Per Cent | Zinc,<br>Per Cent | Copper Added,<br>oz.  |
| 90                  | 10               | 0                 | 0                 | 4                     |
| 88                  | 10               | 0                 | 2                 | 2                     |
| 88                  | 8                | 0                 | 4                 | 1½                    |
| 87                  | 6                | 2                 | 5                 | 1½                    |
| 85                  | 5                | 5                 | 5                 | 1½                    |
| 80                  | 10               | 10                | 0                 | 4                     |



MODULUS OF ELASTICITY OF METAL POURED AT 2200°F IS 12,600,000

FIG. 3.—PROPERTIES OBTAINED ON AN ALLOY (90-10 TYPE) CONTAINING 89.65 PER CENT COPPER, 9.75 PER CENT TIN, 0.15 PER CENT LEAD, 0.10 PER CENT ANTIMONY, REMAINDER ZINC AT VARIOUS POURING TEMPERATURES.



MODULUS OF ELASTICITY OF METAL POURED AT 2200°F IS 12,777,000

\* BARS BROKE AT NECK AND ACTUALS ARE EQUAL OR GREATER

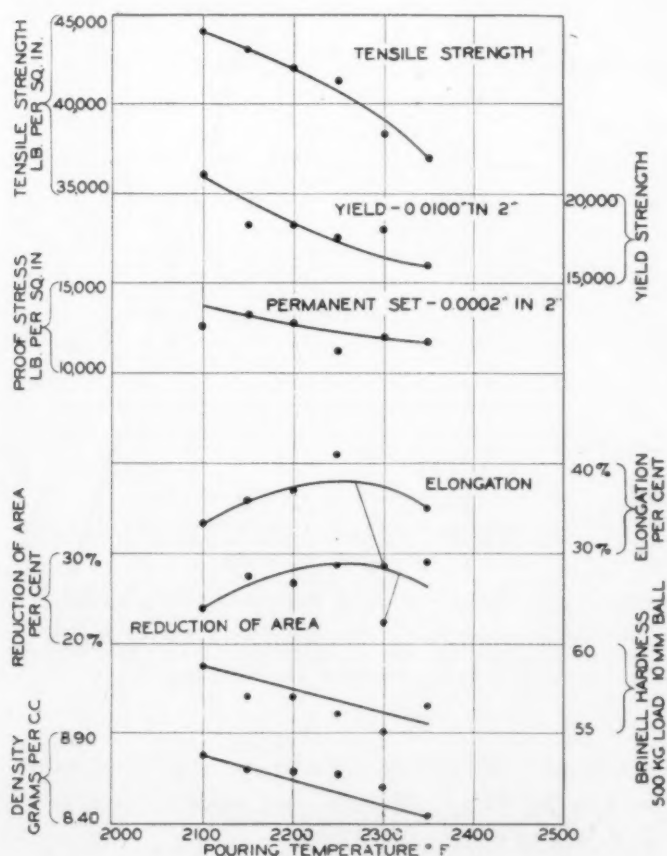
FIG. 4—PROPERTIES OBTAINED ON AN ALLOY (88-10-2 TYPE) CONTAINING 88.25 PER CENT COPPER, 9.50 PER CENT TIN, 0.10 PER CENT ANTIMONY, 0.20 PER CENT LEAD, REMAINDER ZINC AT VARIOUS POURING TEMPERATURES.

### Test Bars

50. Fig. 9 shows the side-feed bar patterns used to cast the test bars from which the results were obtained for the red brass and tin bronze that are plotted in Figs. 3, 4, 5, 6 and 7 and the single keel bar used to secure the data on manganese bronze shown in Fig. 8.

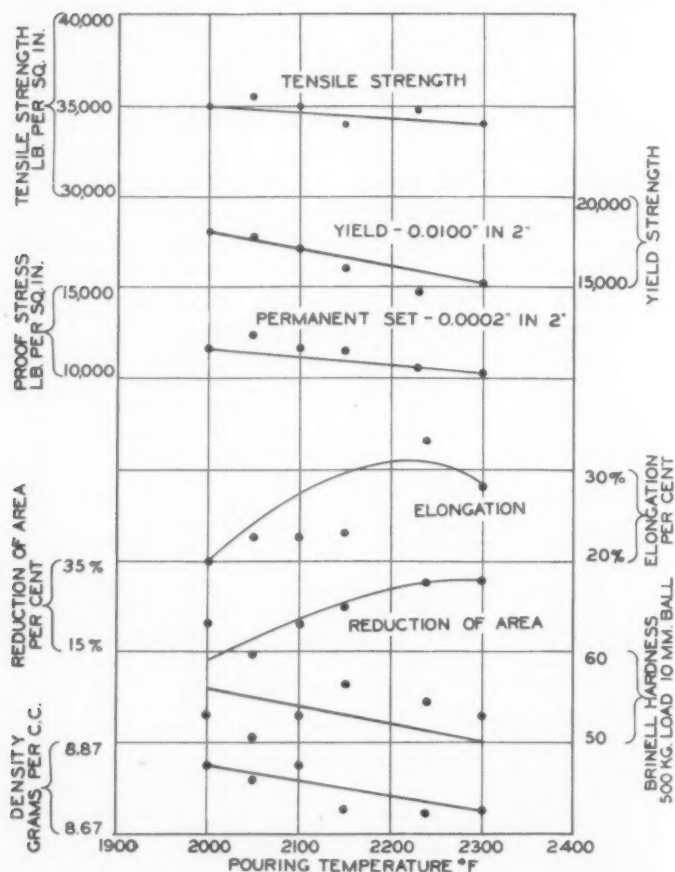
51. The side-feed bar was used because it can be produced in the mold with the casting on the same gate and the inspector does not have to be on hand to witness the casting of the bar.

52. This practice is being used in many plants and shows merit, as the side riser can be increased in height when necessary, to feed without waste of metal. The dimensions are the same as the A.S.T.M. and Navy bars, and the web is the same thickness. The riser is placed on the side to facilitate molding and placing



MODULUS OF ELASTICITY OF METAL POURED AT 2150°F IS 16,600,000

FIG. 5—PROPERTIES OBTAINED ON AN ALLOY (87-6-2-5 TYPE) CONTAINING 88.10 PER CENT COPPER, 5.64 PER CENT TIN, 1.84 PER CENT LEAD, 0.19 PER CENT ANTIMONY, 0.20 PER CENT IRON, 0.64 PER CENT NICKEL, REMAINDER ZINC AT VARIOUS POURING TEMPERATURES.



MODULUS OF ELASTICITY OF METAL POURED AT 2150° IS 12,800,000

FIG. 6—PROPERTIES OBTAINED ON AN ALLOY (85-5-5-5 TYPE) CONTAINING 84.65 PER CENT COPPER, 4.67 PER CENT TIN, 4.80 PER CENT LEAD, 0.23 PER CENT IRON, 0.17 PER CENT ANTIMONY, 0.36 PER CENT NICKEL, REMAINDER ZINC AT VARIOUS POURING TEMPERATURES.

in the flask with the casting. This saving is a considerable item to those who bid for specifications work where a bar must be cast with each heat or piece.

53. Where time and economy are not factors, it is advisable to use the recognized A.S.T.M., vertically-fed bar, as the above illustration is only a modified substitute.

## OBSERVATIONS ON MELTING

54. In the preceding subject matter, all mention of any phenomena observed in melting has been avoided so as not to confuse the reader or issue.

55. Considerable research and worthy deductions have been advanced on this subject and the writer will try to correlate them so as to further a better understanding of the cycle taking place in melting an alloy from the stage of a solid to a liquid and return. However, it is not to be expected all will agree on this cycle.

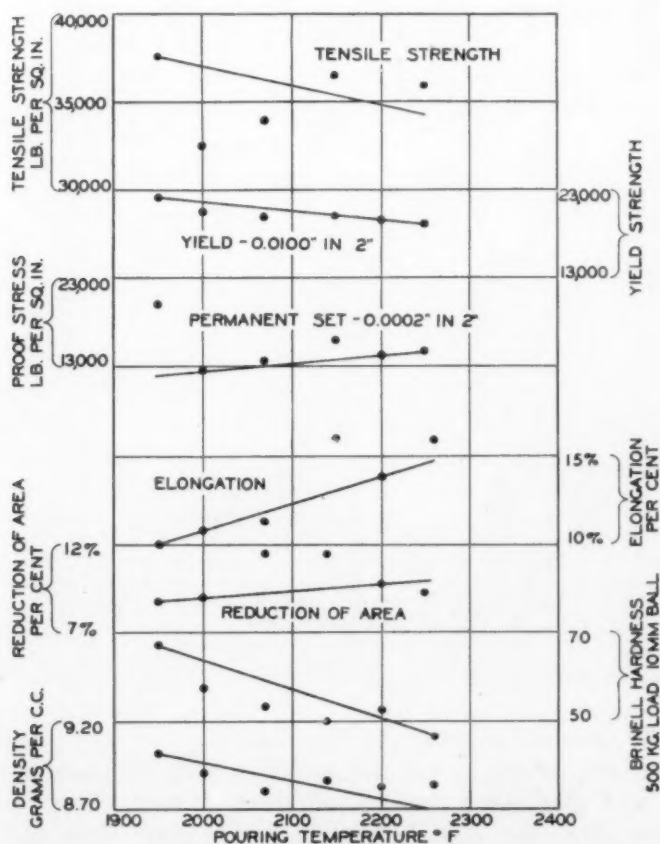


FIG. 7.—PROPERTIES OBTAINED ON AN ALLOY (80-10-10 TYPE) CONTAINING 78.85 PER CENT COPPER, 9.67 PER CENT TIN, 9.60 PER CENT LEAD, 0.25 PER CENT ANTIMONY, 0.05 PER CENT IRON, 0.70 PER CENT NICKEL, REMAINDER ZINC AT VARIOUS POURING TEMPERATURES.

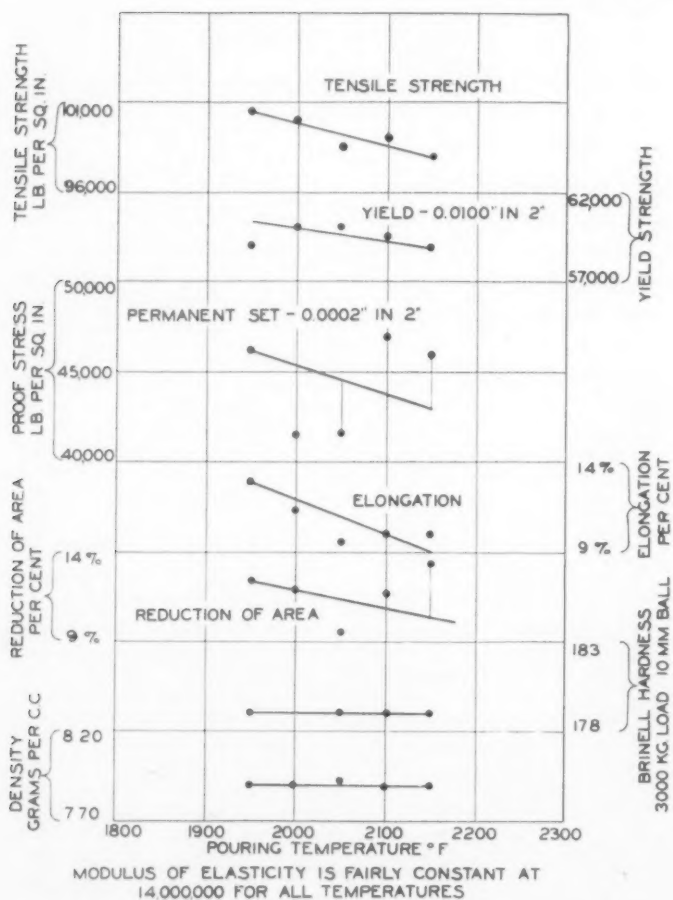


FIG. 8—PROPERTIES OBTAINED ON AN ALLOY (HIGH STRENGTH MANGANESE BRONZE) CONTAINING 68.85 PER CENT COPPER, TIN TRACE, 0.25 PER CENT LEAD, 1.73 PER CENT IRON, 4.12 PER CENT ALUMINUM, 2.74 PER CENT MANGANESE, 0.20 PER CENT NICKEL, REMAINDER ZINC AT VARIOUS POURING TEMPERATURES.

56. For all practical purposes, let it be said that when the solid metal changes to a liquid, metal gives up its gases and re-absorption takes place upon superheating. It is in this relatively gas-free state, just after liquidation, that a silver sheen appears on the bath. All metals and their alloys exhibit this phenomena. This sheen can be seen best by pulling back the covering on the bath in a reducing atmosphere.

57. There is not a melter who has not seen this phenomena but only in rare cases has it been connected in the cycle of events. It is in this gas-free state that the best physical properties lie.

58. In well operated furnaces, this sheen can be prolonged right up to the pouring temperatures. If it should start to disappear before pouring on red brass and tin bronzes, it can be partially restored by additions of phosphorus or zinc.

59. To explain this phenomena in another light, gas in metal is held in an unstable state and the amount that can be held is dependent on the temperature.

60. Any addition of a metal after the furnace is shut off, some having far more effect than others, results in readjustment of the bath and the releasing of gas. For this reason, the addition of zinc, when pulling a heat, is highly recommended where it will replace that which is lost in melting.

61. In alloys where phosphorus or zinc is not permissible, other metals are compounded to liberate the absorbed gases.

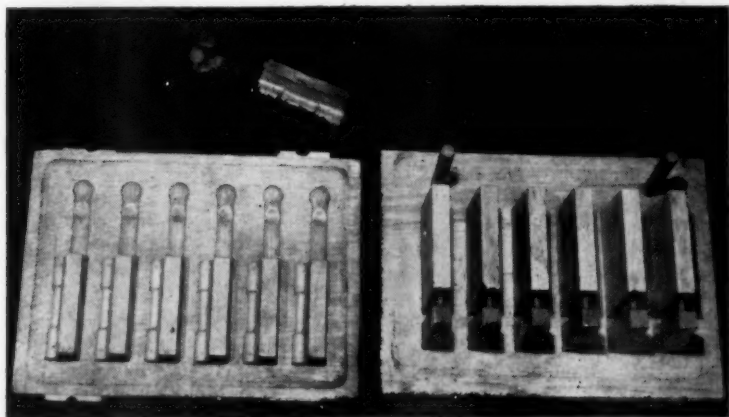


FIG. 9.—PATTERNS USED TO CAST TEST BARS FROM WHICH THE RESULTS IN FIGS. 3, 4, 5, 6, 7 AND 8 WERE OBTAINED.

## DISCUSSION

*Presiding:* W. J. LAIRD, Westinghouse Electric & Mfg. Co., East Pittsburgh, Pa.

B. A. MILLER:<sup>1</sup> There are a few points I would like to stress. Mr. George spoke of the introduction of the raw materials to the crucible. I cannot stress that too highly, especially so when he states that the raw material must never be allowed to go beyond the mushy state in the crucible before the introduction of other raw materials. There has been some sad experience along the line of the introduction of gases which, as he has illustrated, will give you purging of the metal.

Another point I would like to bring out in Mr. George's talk is the pouring temperature of castings and test bars. I would rather put it as the temperature at which the metal comes to rest in the mold. We have found by recording pyrometric tests that there is not such leeway on red compositions as shown by Mr. George. We feel that there is probably about a hundred degrees leeway. We have done quite a bit of research work and have found definitely that it is not the pouring temperature but the temperature at which the metal comes to rest, whether it be test bars or castings.

MR. GEORGE: My experience is that cast red metals pass through a range of solidification points due to the different eutectics, and the rate of speed with which they pass through these points is a factor which governs the grain size and gas liberation. I believe some of our so-called bronzes of the manganese type or mixtures of a single eutectic, fit this one point of rest better.

H. M. ST. JOHN:<sup>2</sup> The author has touched lightly on one question over which there has been a great deal of controversy. With respect to the character and effect of the atmosphere which normally exists in the indirect-arc furnace, I would like, as a matter of personal experience, to slightly modify the statement made in paragraph 12, section (3) as to the manner of deciding whether or not the atmosphere in the furnace is oxidizing or reducing by observing the condition of the electrodes.

It is perfectly true that, if we purposely admit oxygen into the furnace during the melting operation so that we produce a definitely oxidizing atmosphere, the electrodes will taper as described. However, it should be remembered also that if the electrodes are overloaded, tapering will result because of the overload regardless of the character of the atmosphere. On the other hand, if the furnace is closed or nearly so, no oxygen being admitted, the normal atmosphere of the indirect-arc type furnace contains a large amount of carbon monoxide. Whether or not this gas is reducing probably depends upon circumstances. My own personal opinion is that, with the brasses and bronzes, carbon monoxide is harmless unless possibly the furnace is tightly closed so as to build up a pressure of gas within the furnace.

<sup>1</sup> Metallurgist, Cramp Brass & Iron Foundries Co., Philadelphia, Pa.

<sup>2</sup> Metallurgist, The Crane Co., Chicago, Ill.

With the furnace closed or nearly so and the atmosphere containing considerable carbon monoxide, the electrodes will burn practically square—which in my opinion represents a reducing or neutral condition rather than an oxidizing condition. The admission of oxygen tapers them.

If instead of melting brass or bronze you are melting copper, which contains cuprous oxide, then carbon monoxide is definitely reducing and curiously enough, the electrodes will taper. The tapered condition is not a result of oxidizing atmosphere but a definitely reducing atmosphere.

If you melt aluminum under these same conditions, not taking any precautions to prevent this particular effect, you will find that carbon monoxide is oxidizing. A layer forms on the bath consisting of a mixture of aluminum oxide and aluminum carbide. Leakage of air from the outside of the furnace supplies the necessary oxygen and again the electrodes taper. So it is perfectly possible to get a tapering of electrodes with either an oxidizing or a reducing atmosphere but not with a neutral atmosphere.

The point has been stressed that at least slightly oxidizing atmosphere is desirable in melting brass and bronze. I will agree with that thoroughly, if you are talking about fuel-fired furnaces. But I think a good many would agree that if we could always maintain a truly neutral atmosphere, this perhaps would be quite ideal. The point is that it is definitely hard to do in the oil or gas-fired furnace but possible in the indirect-arc furnace, if other conditions are maintained as they should be.

MR. GEORGE: I cannot conceive of an absolutely neutral atmosphere existing in any type furnace. I believe it is either one side or the other, and to bring this point out, if we could obtain an absolutely neutral atmosphere, I believe we could melt copper and pour it into castings without any addition.

I admit that I do not understand all the phenomena that go on within the electric furnace. I might say that I helped design some of the electric furnaces on the market 20 years ago, and we knew very little about them. I still think there are a lot of researches that can be brought forth on this type of equipment.

MR. ST. JOHN: Carbon monoxide, as I see it, is definitely reducing with respect to copper; definitely oxidizing with respect to aluminum at high temperatures and probably neutral or very nearly so with respect to brasses and bronzes.

CHAIRMAN LAIRD: I heartily agree with the comments so far as the desirability of a slightly oxidizing atmosphere in melting is concerned, inasmuch as that is the condition that we are normally equipped to combat.

I was a little puzzled by Mr. George's reasoning in the mechanics of just what takes place when he shows in Fig. 2 that phosphorus cor-

rects a condition which exists either as the result of an oxidizing or reducing atmosphere. I think we all are agreed that phosphorus combats an oxidizing condition but the mechanics of how it goes about combating a reducing one is something that I cannot quite visualize.

G. K. EGGLESTON:<sup>3</sup> Did the author say that any metal with a high affinity for oxygen would be a good degasifier? From our experience phosphorus will deoxidize but I have never seen any case where it would give degasification.

MR. GEORGE: It is my observation that, whether it is phosphorus or any other element, those with a greater affinity for oxygen than the bath will liberate gas. We know, of course, of cases where castings have become gasified and, with the addition of phosphorus, this gas disappeared.

In these particular set-ups, we use one and a half ounces of 15 per cent phosphor-copper per each 100 lb. when shutting off the heat. My observation is that phosphor-copper is used more as a degasifier than it is as a deoxidizer. Many people believe that oxides and gas are the same thing. They are not. Oxidized metal is on one side of the neutral zone and gas is on the other. If the metal is oxidized, we only need phosphorus to increase the fluidity and decrease the oxides. We do not have the gas holes on the oxidized side unless we have an excess amount of oxygen because it attacks the burnable material in the cores thus producing gas holes next to the core surface. Phosphorus liberates gas within brass and bronze castings the same as silicon liberates it with copper. That is my observation.

<sup>3</sup> Metallurgist, Detroit Lubricator Corp., Detroit, Mich.

## The Effect of Varying the Silicon Content of Cast Iron

By FREDERICK G. SEFING\*, NEW YORK, N. Y.

1. The use of silicon to control the mechanical properties of gray iron has been known for many years. Early investigational work developed the fact that increasing the silicon lowered the strength and hardness and decreased the density. This was true for the irons containing 3.40 to 3.75 per cent total carbon used in these early investigations. These effects of silicon were so well established that we have presumed silicon to have the same effects on gray iron of lower total carbons.

2. It has been found in the investigation reported in this paper, that increasing the silicon content in progressively lower total carbon irons, tends to increase the tensile strength. Furthermore, sectional sensitivity decreases with increasing silicon from 1.00 per cent to the level which produces a fully pearlitic structure, beyond which the section sensitivity again increases at lower hardness levels.

3. The results presented here show that the tensile strength increases about 5000 lb. per sq. in. for each 0.25 per cent drop in total carbon from 3.50 to 2.75 per cent.

### PRODUCTION OF TEST BARS

4. Four series of irons, including 13 heats of 250 lb. each, were made in an indirect-arc electric furnace. The same base metals, pig iron, cupola remelt pigs, steel and ferrosilicon, were used in varying proportions to produce the four series of irons whose total carbons were 2.75, 3.00, 3.35 and 3.50 per cent. The silicon content of each series was varied between 1.25 and 2.50 per cent. The analyses of each tap are given in Table 1.

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NOTE: This paper was presented at a Gray Iron Session of the 44th A.F.A. Convention, May 9, 1940, Chicago, Ill.

5. The procedure was the same for each heat in order to reduce the variables of melting practice to a minimum. All the materials for the heat were charged into the hot furnace, varying the proportions of steel and the pig to obtain the desired carbon content and making suitable ferrosilicon additions to the cold charge to obtain the desired silicon. The melt was ready to be tapped at 2800 to 2850°F. in from 50 to 75 min.

6. While tapping weighed, 100-lb. portions of the melt, 0.10 per cent silicon, as 85 per cent ferrosilicon, was added to the ladle. The metal was poured into the molds at 2600 to 2650°F.

7. Each 100 lb. of metal was poured into the following molds:

1 mold of 2 bars, 2 x 4 x 6-in.

1 mold of 2 bars,  $\frac{1}{2}$  x 1 x 6-in.

6 molds of one arbitration bar 1.20-in. diam. x 21-in. long (A.S.T.M.—A48-36)

8. The rectangular bars were made in horizontal green sand molds, held to constant specifications and rammed to the same hardness. The arbitration bars were made in dry sand vertical molds. The castings were cooled to room temperatures in the sand.

#### TESTS

9. Rockwell hardness tests were made on each type of test bar and Brinell hardness tests were made only on the two larger sizes. Accurate Brinell hardness readings could not be obtained on the small size bar. The hardness tests were made on each size on a surface cut through the center of the 6-in. length of the rectangular bars and near the center of the arbitration bars. One hardness was taken in the center and two midway between the center and edge. The average of these six readings (2 bars) was regarded as the hardness of the casting and is given in Table 1.

10. Two arbitration test bars from each tap were tested for transverse load, deflection and tensile strength, according to the methods set forth in the A.S.T.M. specification A48-36. These values also are tabulated in Table 1.

11. Each transverse load, deflection and tensile strength value given in Table 1, is an average of two readings. Each hardness value of Table 1 is an average of six readings. For each heat, two complete sets of values are given, one for each tap, to show the constancy in properties of each heat. Averages of the values for

each heat were used to prepare the set of curves shown in Figs. 1 and 2.

#### DISCUSSION OF TEST DATA

12. From Figs. 1 and 2, it will be seen that the spread of hardness between the light and heavy castings increases with increasing silicon in the 3.50 per cent total carbon iron. Furthermore, the tensile strength of this series of irons decreases as the silicon increases.

13. When, however, we observe the effects of silicon on the 3.35 per cent total carbon iron, the spread of hardness between the light and heavy castings decreases up to 1.50 per cent silicon and remains constant up to 2.00 per cent silicon. There is no appreciable change in the strength properties of this carbon level with the silicon varying between 1.25 and 2.00 per cent.

14. In the series of irons containing 3.00 per cent total carbon, there is a marked decrease in the section sensitivity as the silicon increases to 1.60 per cent. It remains quite constant then as the silicon increases from 1.60 to 2.15 per cent beyond which the section sensitivity again becomes evident at lower hardness levels. It also will be noted that the tensile strength remains about the same as the silicon increases. The slight increase in strength in the 2.15 per cent silicon iron is probably due to the 2.90 per cent total carbon.

15. The 2.75 per cent total carbon irons show a reduction in section sensitivity only with more than 2.00 per cent silicon. At 2.50 per cent silicon, these irons show a surprisingly constant hardness in the light and heavy section castings. In this series of irons, an increase in strength properties was observed as the silicon content increased from 1.50 to about 2.00 per cent. With further increase in silicon, however, the strength properties decreased.

16. From the strength curves, it will be seen that the tensile strength increases from about 25,000 to 40,000 lb. per sq. in. as the total carbon decreases from 3.50 to 2.75 per cent. This is an increase in tensile strength of about 5000 lb. per sq. in. with a reduction of 0.25 per cent total carbon from 3.50 to 2.75 per cent.

17. For the greatest constancy of properties of gray iron, the relationship of the total carbon and silicon may be expressed by the following equation:

$$\text{Per Cent Total Carbon} + 0.60 \text{ Per Cent Silicon} = 4.25 \text{ Per Cent.}$$

**Table 1**  
CHEMICAL AND PHYSICAL PROPERTIES OF ELECTRIC FURNACE HEATS

| Heat No. | Total Carbon, Per Cent | Silicon, Per Cent | Sulphur, Per Cent | Phos- phorus, Per Cent | Manganese, Per Cent | Transverse Load, lb. | Def., in. | Tensile Strength, lb. per sq. in. | Brinell   |          |           | Hardness |                |           | Differences <sup>a</sup> |
|----------|------------------------|-------------------|-------------------|------------------------|---------------------|----------------------|-----------|-----------------------------------|-----------|----------|-----------|----------|----------------|-----------|--------------------------|
|          |                        |                   |                   |                        |                     |                      |           |                                   | Large Bar | Arb. Bar | Large Bar | Arb. Bar | Rockwell B Bar | Small Bar |                          |
| 74A      | 2.78                   | 1.47              | 0.03              | 0.18                   | 0.60                | 2080                 | 0.158     | 36,500                            | 207       | 212      | 93C       | 94B      | 111A           |           | 18                       |
| B        | 2.77                   | 1.49              |                   |                        |                     | 2360                 | 0.168     | 37,200                            | 212       | 223      |           | 95       | 107            |           | 12                       |
|          |                        |                   |                   | Average                |                     | 2220                 | 0.162     | 36,800                            | 210       | 217      | 94        | 96       | 109            |           | 15                       |
| 70A      | 2.72                   | 2.01              |                   |                        |                     | 2670                 | 0.192     | 41,100                            | 201       | 217      | 91        | 96       | 106            |           | 15                       |
| B        | 2.73                   | 1.99              |                   |                        |                     | 2480                 | 0.181     | 41,600                            | 201       | 223      | 93        | 93       | 110            |           | 17                       |
|          |                        |                   |                   | Average                |                     | 2575                 | 0.187     | 41,400                            | 201       | 220      | 92        | 93       | 108            |           | 16                       |
| 71A      | 2.71                   | 2.25              |                   |                        |                     | 2370                 | 0.170     | 42,200                            | 217       | 229      | 97        | 99       | 103            |           | 6                        |
| B        | 2.71                   | 2.17              |                   |                        |                     | 2500                 | 0.170     | 41,700                            | 217       | 223      | 96        | 96       | 105            |           | 9                        |
|          |                        |                   |                   | Average                |                     | 2435                 | 0.170     | 42,000                            | 217       | 226      | 96        | 98       | 104            |           | 8                        |
| 72A      | 2.72                   | 2.48              |                   |                        |                     | 2370                 | 0.170     | 40,700                            | 212       | 217      | 98        | 96       | 99             |           | 1                        |
| B        | 2.70                   | 2.49              |                   |                        |                     | 2300                 | 0.188     | 39,400                            | 217       | 223      | 97        | 96       | 99             |           | 2                        |
|          |                        |                   |                   | Average                |                     | 2335                 | 0.169     | 40,100                            | 215       | 220      | 97        | 96       | 99             |           | 2                        |
| 73A      | 2.98                   | 1.37              | 0.04              | 0.16                   | 0.65                | 2150                 | 0.187     | 34,700                            | 183       | 201      | 89        | 92       | 105            |           | 16                       |
| B        | 3.01                   | 1.36              |                   |                        |                     | 2230                 | 0.164     | 35,500                            | 179       | 207      | 88        | 92       | 113            |           | 25                       |
|          |                        |                   |                   | Average                |                     | 2190                 | 0.176     | 35,000                            | 181       | 204      | 88        | 92       | 109            |           | 21                       |
| 76A      | 3.08                   | 1.61              |                   |                        |                     | 2280                 | 0.205     | 34,400                            | 183       | 212      | 90        | 94       | 95             |           | 5                        |
| B        | 3.05                   | 1.62              |                   |                        |                     | 2120                 | 0.181     | 34,400                            | 183       | 201      | 92        | 93       | 98             |           | 6                        |
|          |                        |                   |                   | Average                |                     | 2205                 | 0.193     | 34,400                            | 183       | 206      | 91        | 93       | 97             |           | 6                        |

|     |      |      |         |       |        |     |     |    |    |     |    |
|-----|------|------|---------|-------|--------|-----|-----|----|----|-----|----|
| 77A | 2.88 | 2.15 | 2140    | 0.218 | 38,100 | 192 | 212 | 94 | 95 | 97  | 3  |
| B   | 2.90 | 2.15 | 2330    | 0.195 | 38,000 | 197 | 217 | 94 | 95 | 99  | 5  |
|     |      |      | 2385    | 0.207 | 38,100 | 195 | 215 | 94 | 95 | 98  | 4  |
|     |      |      | Average |       |        |     |     |    |    |     |    |
| 82A | 3.02 | 2.36 | 2270    | 0.299 | 35,400 | 143 | 183 | 80 | 86 | 94  | 14 |
| B   | 3.03 | 2.42 | 2260    | 0.278 | 34,100 | 152 | 183 | 79 | 87 | 96  | 17 |
|     |      |      | 2265    | 0.288 | 34,800 | 148 | 183 | 79 | 86 | 95  | 16 |
|     |      |      | Average |       |        |     |     |    |    |     |    |
| 84A | 3.33 | 1.25 | 2120    | 0.228 | 30,900 | 159 | 187 | 82 | 88 | 109 | 27 |
| B   | 3.34 | 1.28 | 2060    | 0.206 | 31,000 | 156 | 179 | 83 | 89 | 110 | 27 |
|     |      |      | 2090    | 0.217 | 31,000 | 158 | 183 | 83 | 88 | 110 | 27 |
|     |      |      | Average |       |        |     |     |    |    |     |    |
| 85A | 3.31 | 1.54 | 2090    | 0.230 | 31,400 | 163 | 187 | 81 | 87 | 94  | 13 |
| B   | 3.34 | 1.55 | 2050    | 0.217 | 30,700 | 156 | 179 | 84 | 85 | 94  | 10 |
|     |      |      | 2070    | 0.224 | 31,100 | 160 | 183 | 82 | 86 | 94  | 12 |
|     |      |      | Average |       |        |     |     |    |    |     |    |
| 85A | 3.36 | 1.91 | 2000    | 0.237 | 30,400 | 152 | 179 | 82 | 86 | 94  | 12 |
| B   | 3.35 | 1.97 | 1960    | 0.204 | 29,900 | 159 | 187 | 81 | 87 | 90  | 9  |
|     |      |      | 1980    | 0.221 | 30,200 | 155 | 183 | 81 | 86 | 92  | 11 |
|     |      |      | Average |       |        |     |     |    |    |     |    |
| 80A | 3.32 | 1.42 | 2000    | 0.264 | 27,400 | 156 | 163 | 78 | 84 | 92  | 14 |
| B   | 3.31 | 1.47 | 1980    | 0.262 | 28,100 | 149 | 163 | 83 | 82 | 93  | 10 |
|     |      |      | 1990    | 0.262 | 27,800 | 153 | 163 | 80 | 83 | 92  | 12 |
|     |      |      | Average |       |        |     |     |    |    |     |    |
| 81A | 3.49 | 2.13 | 1880    | 0.261 | 25,700 | 140 | 167 | 77 | 79 | 92  | 15 |
| B   | 3.50 | 2.21 | 1790    | 0.246 | 24,100 | 137 | 156 | 69 | 79 | 91  | 22 |
|     |      |      | 1835    | 0.254 | 24,900 | 138 | 161 | 73 | 79 | 92  | 19 |
|     |      |      | Average |       |        |     |     |    |    |     |    |

<sup>1</sup> Includes 0.10 per cent Silicon as a ladle addition.

<sup>2</sup> Difference in hardness between large and small bar.

\*A = First 100 lb. tap.

B = Second 100 lb. tap.

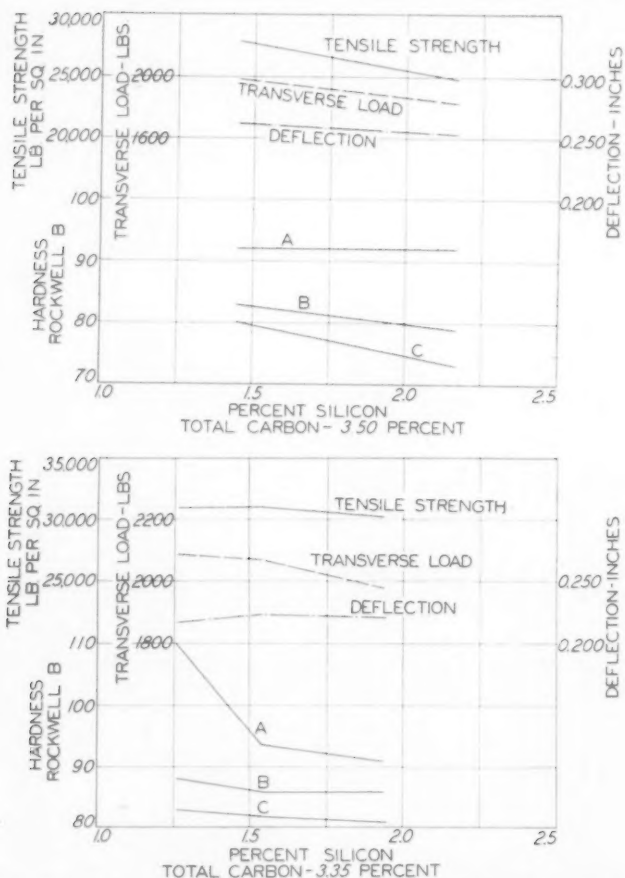


FIG. 1—TOP—TENSILE STRENGTH, TRANSVERSE STRENGTH, DEFLECTION AND HARDNESS VALUES OBTAINED ON A 3.50 PER CENT CARBON CAST IRON WITH VARYING SILICON PERCENTAGES. BOTTOM—SAME FOR 3.35 PER CENT CARBON CAST IRON.

NOTE: Transverse strength, deflection, and tensile strength values obtained on 1.20-in. diameter arbitration test bars. Hardness values are given for each of the test bars cast. A =  $\frac{1}{2}$  x 1 x 6-in. bar. B = 1.2 x 21-in. arbitration bar. C = 2 x 4 x 6-in. bar.

18. By applying this equation to each carbon series shown in Figs. 1 and 2 it will be found that the silicon-carbon relationship for minimum section sensitivity should be about as follows:

| Total Carbon, Per Cent | Silicon, Per Cent |
|------------------------|-------------------|
| 3.50                   | 1.20              |
| 3.35                   | 1.50              |
| 3.00                   | 2.00              |
| 2.75                   | 2.50              |

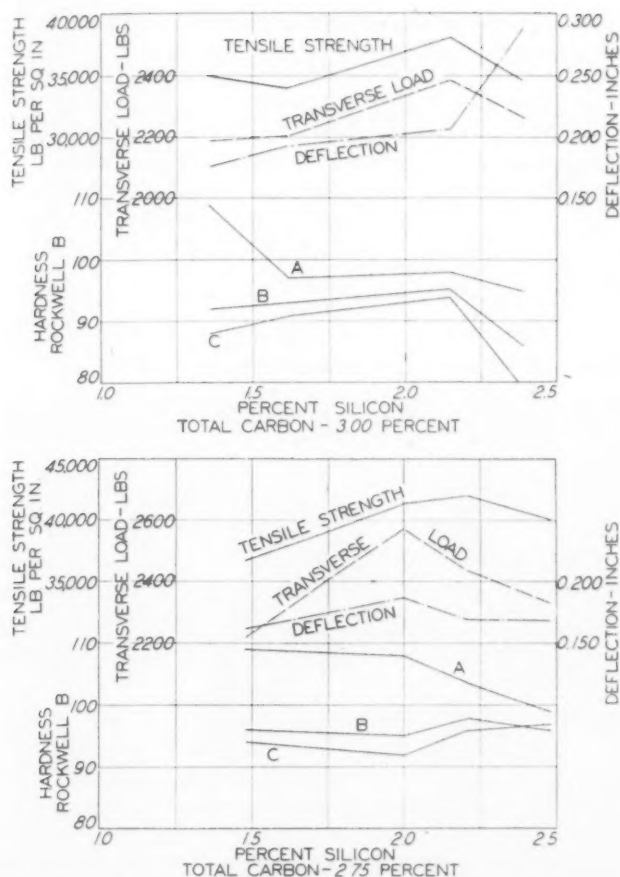


FIG. 2—TOP—TENSILE STRENGTH, TRANSVERSE STRENGTH, DEFLECTION AND HARDNESS VALUES OBTAINED ON A 3.00 PER CENT CARBON CAST IRON WITH VARYING SILICON PERCENTAGES. BOTTOM—SAME FOR 2.75 PER CENT CARBON CAST IRON.

NOTE: Transverse strength, deflection, and tensile strength values obtained on 1.20-in. diameter arbitration test bars. Hardness values are given for each of the test bars cast. A =  $\frac{1}{2}$  x 1 x 6-in. bar. B = 1.2 x 21-in. arbitration bar. C = 2 x 4 x 6-in. bar.

### CONCLUSIONS

19. From the data obtained in this investigation, the following conclusions may be drawn:

1. There exists an optimum silicon content for each carbon level to obtain the minimum section sensitivity, which is indicated by hardness values of the same order between light and heavy sections. The section sensitivity is generally in a

higher hardness range for the low silicon irons and in a lower hardness range for the high silicon irons.

2. The tensile strength decreases with increase of silicon in the 3.50 per cent total carbon iron. However, it changes its response to increasing silicon as the total carbon falls to 2.75 per cent. The tensile strength does not change with increasing silicon at 3.35 and 3.00 per cent total carbon and shows an increase with increasing silicon at 2.75 per cent total carbon.

3. Lowering the total carbon from 3.50 to 2.75 per cent causes an increase in tensile strength of about 5000 lb. per sq. in. for each 0.25 per cent drop in carbon. The hardness of  $\frac{3}{4}$  to 2-in. thick sections increases about 25 points Brinell with each 0.25 per cent carbon drop.

#### ACKNOWLEDGMENTS

20. The author acknowledges the cooperation of the Detroit Edison Company, whose electric furnace was used in these experiments, and the kind criticisms of Dean H. B. Dirks of Michigan State College, under whose authority this work was carried on.

#### DISCUSSION

*Presiding:* W. H. SPENCER, Wilkening Mfg. Co., Philadelphia, Pa.

H. L. WOMACHEL<sup>1</sup> (*Written Discussion*): Work by Crosby and others has established that late additions of 0.25 per cent or more silicon are sometimes necessary to obtain good properties in low carbon irons heated to above 2800°F. The tendency is for incompletely-deoxidized, superheated irons to have abnormal structures in light sections. Abnormal irons often show considerable ferrite in thin sections, and may be soft. In the absence of any photomicrographs in Mr. Sefing's paper, we do not know to what extent the uniformity of hardness with varying section size can be attributed to unfavorable structures in the light sections. Higher values for physical properties are reported in the literature for irons of similar compositions to those described by Mr. Sefing. This would indicate that the irons under discussion may not be normal.

It is generally agreed that hardness numbers are not an accurate index of such properties as tensile and impact strengths, and wear resistance. It would not appear justifiable to conclude that certain compositions have low section sensitivity on the basis of hardness readings alone. More data on the properties of low-carbon, unalloyed irons in

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heavy sections is needed in the literature. Mr. Sefing should continue his investigation with determinations of the physical properties of the irons in the heavy and light sections.

A discussion of the influence of composition and of section size on the properties of cast irons of less than 3 per cent carbon is of limited value unless photomicrographs of the irons are included. Fig. 3 shows the structures of two irons which were cast from the same ladle and have the same chemical analysis as far as carbon, silicon, manganese, phosphorus and sulphur content. Yet they are entirely different in structure and properties. The "abnormal" iron is inferior in tensile properties, in wear resistance, and in endurance limit. Under certain conditions, abnormal irons show large areas of ferrite in the matrix and are likely to be soft in light sections.

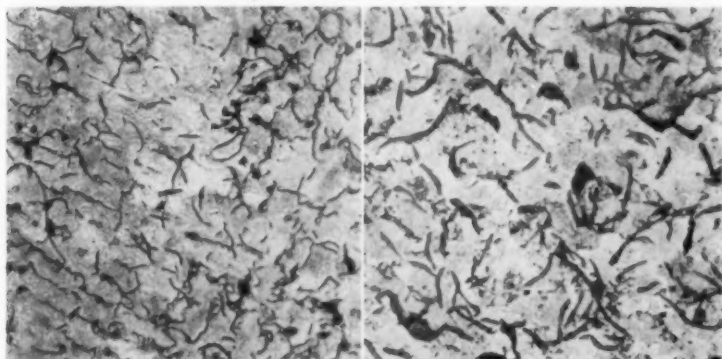


FIG. 3—COMPARISON OF STRUCTURES OF TWO IRONS WITH IDENTICAL CHEMICAL ANALYSES. LEFT—ABNORMAL. RIGHT—NORMAL.

The condition of abnormality is produced by superheating to temperatures above 2800°F. The abnormal condition can be corrected by proper deoxidation just before pouring. In the case of the "normal" iron, the normal condition was brought about by treatment with calcium compounds. The amount of calcium retained in the metal is too small to be detected by ordinary methods of analysis.

Research conducted at Battelle Memorial Institute and by V. A. Crosby, Climax Molybdenum Co., Detroit, has shown that at least 0.25 per cent silicon must be added to the ladle to correct the bad effects of superheating. The melting practice outlined by Mr. Sefing would indicate that the irons on which his figures are based are abnormal. If this is not the case due to some peculiarity in his practice, photomicrographs should be included to show the character of his irons.

The importance of this effect of late additions of deoxidizers or "graphitizers" in present day melting practice is evident from the following quotation from the 1940 edition of the *Cast Metals Handbook*.

"However, even in higher strength irons, progress is being made so that, in some foundries, lower silicon contents are being used than indicated above. These lower contents are made possible by the use of potent graphitizing agents." Work done on high strength iron should be conducted according to accepted practice, and should include photomicrographs or a description of the structure of the irons.

Reference to the data in Table 1 shows that with very low silicon contents, the irons are very hard in light sections and that as silicon and carbon are increased the irons became very soft in heavy sections. I do not believe that this will be a surprise to the gray iron metallurgist. It has long been realized that, in dealing with castings of varying section size, it is necessary to regulate the silicon content carefully to effect a compromise. This selection of silicon content is not always made on the basis of hardness readings taken beneath the surface of the castings. Susceptibility to chilled edges and graphite distribution in heavy sections must also be considered.

All of the data on physical properties is based on tests run on the 1.2-in. diameter round section. It is implied, for example, that increasing the silicon content of the 3 per cent carbon iron from 1.37 to 2.15 per cent has not been accompanied by a loss of strength in the heavy section. In general, there is good correlation between hardness and other properties, but this is not always the case and a more careful study of the influence on the other properties would be desirable in a study of this kind.

In taking hardness readings in heavy sections, metallurgists are interested in the distribution of hardness across the section. Heavy sections are likely to show a very soft core. The figures presented in this paper are average values obtained from a number of readings taken across the entire section. A diagram should be presented to show the exact method of sectioning the castings and the distribution of hardness values across the section should be recorded.

In Table 1, it is implied that a round section 1.2-in. in diameter is intermediate in size between two rectangular sections cast in green sand. This is not necessarily the case. A step bar casting is widely used in studying the influence of section size. It is surprising that such a bar was not employed in this study.

**MR. SEFING:** The matter of ferrosilicon additions to the ladle is of great importance in controlling graphite structures. I examined some of these irons under the microscope and found a great many of them were badly dendritic. I have learned, since doing this work, that the section sensitivity becomes even less with late silicon addition than with those irons not so treated. I rather think therefore that the sensitivity of the irons reported here was somewhat at its worst.

Of course, it is understood that the tensile strength values in the paper were not to be misconstrued as indicating the strength of the heavy section metal. I should like to say this, however; if there is

marked variation in hardness from the edge to the center of a heavy casting, it is the kind of a casting that no foundryman wishes to deliver, because it indicates his pouring practice leaves much to be desired.

If one is making castings, such as machine tools, that are heavy sectioned, they are required to be dense across any section of the machine, as well as in those parts that are drilled or bored out. We have found that, with our pouring practice, the density of the metal was so constant that the hardness variation in the heavy section was surprisingly constant from the center even to the edge of the casting.

We did not record hardnesses directly on the outside surface of the castings to eliminate the intense hardness on the light sections. This we thought would not be quite a fair comparison.

C. H. LORIG<sup>2</sup> (*Written Discussion*): The paper by Mr. Sefing is extremely interesting in that it demonstrates the beneficial effect of silicon on the properties and sectional sensitivity of low carbon gray irons.

In reviewing the properties of the gray irons listed in Table 1, however, one cannot help but wonder whether the irons which Mr. Sefing prepared in the indirect-arc furnace were not of the so-called "modified" or "dendritic" type, since in no case were the properties as good as they might have been. This is particularly true of the low and medium carbon content irons. An examination of the fractures of the broken transverse bars or of the microstructures would have indicated how far the irons were from being normal in structure.

Mr. Sefing added 0.10 per cent silicon as 85 per cent ferrosilicon to the iron in the ladle before it was poured. One would judge that this addition was insufficient in amount to produce an entirely normal structure and that, in consequence, the cast irons showed relatively low tensile and transverse strengths and low deflection values.

Just how effective larger ladle additions of ferrosilicon can be is illustrated in Table 2 of properties of cast irons covering a wide range in silicon and carbon contents. The first series of irons were made as 100-lb. heats in a high-frequency, induction furnace from the same melting stock comprising pig iron, steel scrap, ferrosilicon, ferromanganese, iron sulphide, and ferrophosphorus. The complete charge was in the furnace at the moment of melt-down. The power input into the furnace was adjusted to heat the iron from the melt-down to 2900°F. in 10 min. There were no ladle additions and the metal was cooled in the ladle to 2500°F. before it was cast. The second series of irons, which were treated with ferrosilicon, was prepared in an indirect-arc furnace from a charge consisting principally of pigs of cupola iron and steel scrap. The melts were heated to about 2800°F. in the furnace, poured into ladles, and held until the temperature has dropped to 2500°F. before casting. One-half per cent silicon, as 75 per cent ferrosilicon, was added to the irons in the ladle.

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Table 2

PROPERTIES OF ELECTRIC FURNACE CAST IRONS VARYING IN SILICON  
AND CARBON CONTENTS—EFFECT OF SILICON TREATMENT

| Iron   | Chemical Composition, Percent—    |      |      |       |       | Tensile                      | Transverse       | Deflec-      | Brinell<br>Hardness <sup>a</sup> |
|--|-----------------------------------|------|------|-------|-------|------------------------------|------------------|--------------|----------------------------------|
|  | C                                 | Si   | Mn   | S     | P     | Strength,<br>lb. per sq. in. | Strength,<br>lb. | tion,<br>in. |                                  |
|  | First Series—No Silicon Treatment |      |      |       |       |                              |                  |              |                                  |
| 1  | 2.48                              | 1.52 | 0.70 | 0.059 | 0.071 | 40,000                       | 2490             | 0.169        | 229                              |
| 5  | 2.56                              | 2.15 | 0.74 | 0.066 | 0.089 | 36,000                       | 2400             | 0.169        | 226                              |
| 7  | 2.48                              | 2.42 | 0.72 | 0.063 | 0.092 | 34,500                       | 2450             | 0.166        | 221                              |
| 9  | 2.58                              | 3.07 | 0.72 | 0.07  | 0.091 | 38,000                       | 2300             | 0.156        | 235                              |
| 11   | 2.84                              | 1.68 | 0.70 | 0.068 | 0.085 | 36,000                       | 2510             | 0.200        | 226                              |
| 13   | 2.88                              | 1.87 | 0.67 | 0.056 | 0.103 | 37,000                       | 2490             | 0.228        | 206                              |
| 15   | 2.83                              | 2.13 | 0.69 | 0.059 | 0.110 | 34,000                       | 2490             | 0.199        | 215                              |
| 17   | 2.88                              | 2.62 | 0.71 | 0.059 | 0.107 | 32,000                       | 2460             | 0.206        | 193                              |
| 19   | 2.83                              | 3.16 | 0.69 | 0.076 | 0.099 | 31,000                       | 2370             | 0.213        | 176                              |
| 21   | 3.10                              | 1.41 | 0.65 | 0.060 | 0.095 | 35,500                       | 2400             | 0.221        | 197                              |
| 23   | 3.08                              | 1.64 | 0.70 | 0.060 | 0.089 | 34,500                       | 2375             | 0.239        | 194                              |
| 25   | 3.03                              | 2.14 | 0.60 | 0.056 | 0.090 | 34,500                       | 2380             | 0.220        | 208                              |
| 27   | 3.07                              | 2.62 | 0.72 | 0.068 | 0.088 | 30,000                       | 2390             | 0.233        | 177                              |
| 35   | 3.38                              | 1.10 | 0.67 | 0.067 | 0.101 | mottled                      | 2490             | 0.238        | ...                              |
| 37   | 3.35                              | 1.42 | 0.60 | 0.069 | 0.106 | 30,000                       | 2210             | 0.230        | 194                              |
| 31   | 3.31                              | 1.68 | 0.68 | 0.064 | 0.090 | 31,000                       | 2190             | 0.246        | 194                              |
| 33   | 3.34                              | 2.14 | 0.69 | 0.061 | 0.092 | 30,000                       | 2220             | 0.244        | 186                              |
| 41   | 3.31                              | 2.51 | 0.67 | 0.071 | 0.106 | 24,000                       | 1895             | 0.259        | 152                              |
| Second Series—0.50 Per Cent Silicon in Ladle |                                   |      |      |       |       |                              |                  |              |                                  |
| 1a   | 3.44                              | 0.63 | 0.52 | 0.101 | 0.22  | 35,000                       | 3100             | 0.290        | 199                              |
| 4a   | 3.37                              | 1.00 | 0.52 | 0.10  | 0.22  | 40,500                       | 2850             | 0.321        | 205                              |
| 9a   | 3.32                              | 1.38 | 0.54 | 0.099 | 0.23  | 45,000                       | 2850             | 0.308        | 208                              |
| 16a  | 3.33                              | 1.72 | 0.57 | 0.108 | 0.22  | 38,500                       | 2800             | 0.355        | 196                              |
| 19a  | 3.36                              | 1.84 | 0.54 | 0.087 | 0.21  | 36,000                       | 2700             | 0.348        | 190                              |
| 60a  | 3.40                              | 2.50 | 0.58 | 0.091 | 0.22  | 26,500                       | 2200             | 0.314        | 175                              |
| 22a  | 3.16                              | 0.71 | 0.57 | 0.119 | 0.23  | white                        | 2450             | 0.124        | ...                              |
| 25a  | 3.07                              | 1.14 | 0.55 | 0.116 | 0.23  | 51,000                       | 3250             | 0.342        | 219                              |
| 30a  | 3.16                              | 1.54 | 0.57 | 0.106 | 0.22  | 48,500                       | 3250             | 0.379        | 213                              |
| 36a  | 3.15                              | 1.93 | 0.59 | 0.108 | 0.23  | 46,000                       | 3250             | 0.356        | 208                              |
| 41a  | 3.12                              | 2.61 | 0.59 | 0.096 | 0.24  | 41,000                       | 3000             | 0.345        | 201                              |
| 44a  | 2.94                              | 1.11 | 0.54 | 0.094 | 0.23  | 53,500                       | 3400             | 0.387        | 228                              |
| 47a  | 2.90                              | 1.57 | 0.57 | 0.097 | 0.21  | 55,500                       | 3500             | 0.347        | 225                              |
| 52a  | 2.91                              | 2.05 | 0.59 | 0.096 | 0.23  | 54,000                       | 3400             | 0.299        | 233                              |
| 57a  | 2.89                              | 2.52 | 0.62 | 0.093 | 0.22  | 55,500                       | 3450             | 0.334        | 230                              |

\* Brinell hardness measured at half radius point on 1.2-in. bar. All tests made on 1.2-in. bar. Transverse test with 18-in. centers. Tensile specimens taken from broken transverse bars.

The properties given in Table 2 are the average of two determinations.

The fact that the irons were made in two different furnaces using different materials in the charge had no marked effect on the outcome of the experiments. We have frequently duplicated results reported for the high frequency furnace irons with irons made in the indirect-arc furnace using no ladle additions, and have duplicated the excellent properties of the indirect-arc furnace irons by making ladle additions of silicon to high frequency furnace irons.

One of the most obvious differences between irons of the two series is the fact that they possess properties of entirely different scale of values. The irons of the first series had sooty fractures and were highly modified in structure. They illustrate the influence of this type of structure on properties and show that the tensile and transverse strengths and the deflection properties are made abnormally low. Hardness is not greatly affected. On the other hand, irons of the second series were

normal in structure, i.e. the graphite in these irons was in flake form and properties were correspondingly superior to the irons of the first series.

It should be noted that only irons of the second series containing about 2.90 per cent carbon showed a slight increase in tensile strength with increase in silicon content. In all other cases, except for the low silicon irons that tended to be mottled, the effect of increasing the silicon content was to lower the tensile strength. The results on the second series of irons seem to bear out Mr. Sefing's conclusion that, for the higher carbon irons, the tensile strength decreases with increase in silicon, but that this response to increasing silicon changes as the total carbon falls below 3.00 per cent. These results also tend to support his conclusion that lowering the total carbon from 3.50 to 2.75 per cent causes an increase in tensile strength of several thousand pounds per square inch for each 0.25 per cent drop in carbon. Here, as would be expected, the silicon effect comes into play making the spread between properties of the high silicon irons of low and high total carbon contents much greater than is the case for low silicon irons of low and high total carbon.

The above data are offered chiefly as supporting evidence of the effect of silicon in plain irons varying in carbon content. They also illustrate the tremendous effect of melting procedure on properties of irons of seemingly identical analyses.

F. HOLTBY<sup>3</sup>: In this paper the author states that the total carbon plus 0.6 per cent silicon equals 4.25 per cent. In a book, "*The Microscope in Elementary Cast Iron Metallurgy*," 1939, by Roy M. Allen, which was recently published by the A.F.A., the author states that the silicon plus the total carbon is always equal to a constant if you want a certain type of hardness or tensile strength on cast iron. This is nothing more than just a modification of that; is that right?

In other words, you believe there should be a correction factor in there of this 0.6 per cent.

MR. SEFING: We find people using carbon plus 0.3 per cent silicon, and I thought it would not hurt to add another constant to this series. It happened that I took 0.6 because I wanted to fit it into the Maurer diagram.

I would like to add to that point, that I have found in practice, if working with the heavier sections, 4, 8 or 10-in. sections, that one can use the same formula generally by decreasing the factor of 4.25 per cent in the equation for the section sizes indicated in the paper to about 4 per cent for 4 or 5-in. sections and about 3.8 per cent for a 6 to 10-in. sections.

So one can use the constant on the right of the equation adjusted to the section decided to be used.

<sup>3</sup> University of Minnesota, Minneapolis, Minn.

F. HOLTBY: Would you suggest that if a certain company were trying to hold a depth of chill in their cast iron and their carbons were varying in the cupola and they found out from chemical analyses that the total carbon plus silicon would always be 5, from your experience would you say the depth of chill would always come about the same? I am talking just about the depth of chill.

MR. SEFING: If a carbon is varying as badly as you indicated there and you are holding the silicon content constant, the chill effect will vary inversely to the carbon content.

F. HOLTBY: Maybe I should make it a little clearer. This particular company is pouring a certain number of castings. They have only a certain sized flask and jacket equipment. So from a certain tap of iron, which they know is a certain percent of carbon, they have to take time off, change all their jacket equipment over, and by that time they are back in the 3.5 per cent carbon. They want some way to always have the depth of chill the same on these castings, although they have to pour them at various times in their heats.

I have suggested that if they make a sum total and then add that amount of silicon to the lower carbons to bring it up to a certain definite sum total of the two to get the depth of chill, it might be a help and so far it has worked out successfully or fairly successfully.

I was wondering if you have had any experience in that line.

MR. SEFING: If you are applying this principle to an iron that is running low in carbon and having a deep chill, obviously the thing to do is to make an addition of silicon or any of the graphitizers, which will decrease the chill, then when you lower the high carbon later you need make no addition of a graphitizer. In other words, the foundryman is using the chill test here to control his properties.

## Flowability of Molding Sand<sup>†</sup>

BY PETER E. KYLE,\* CAMBRIDGE, MASS.

### Abstract

*Flowability is defined as the property of a sand which enables it to be forced around a pattern at the proper hardness without producing undesirable conditions at other parts of the mold. Two methods of measuring flowability are discussed and comparisons are drawn with the method suggested by earlier investigations. Of the tests mentioned, the hardness gradient method seems to be the most sensitive. Results of all tests are shown and the flowability of several sands is obtained. These show the effect of moisture on flowability of sands of different fineness. The effect of method of ramming on flowability is indicated. Suggestions for further investigations are also included.*

1. In studying the property of flowability of molding sands, the foundryman is perhaps interested in two phases of the problem, (1) the flow of the sand as force is applied during the molding operation and (2) the flow of the sand due to the weight of molten metal in the mold during the casting operation. The second phase pertains to the ability of the sand to retain the size of mold cavity during casting.

2. In the past, any tendency toward oversize castings, due to mold compression by the molten metal, has been remedied by increasing the mold hardness with additional ramming, squeezing, or jolting. This matter deserves more consideration, particularly from the non-ferrous foundrymen, who should feel the need for casting closer to dimension so as to put their product in keener competition with pressure and gravity die castings.

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† Much of the preliminary work on this problem is recorded in a Master of Science thesis on file at the Mechanical Engineering Department, Massachusetts Institute of Technology. Data from this thesis have been used in the preparation of this paper.

NOTE: This paper was presented at a Foundry Sand Research Session at the 44th A.F.A. Convention, May 8, 1940, Chicago, Ill.

3. The present paper, however, is restricted to consideration of the flow of sand during molding. Among the most important reasons for controlling this property are the need for having the sand pack uniformly around the pattern to give smooth surfaces to the casting and also the desire to produce the mold with the minimum effort in ramming.

#### *Flowability*

4. In the choice of tests to measure flowability, it is necessary to keep in mind some of the things which are implied by the term itself. *Flowability, as applied to molding sands, should indicate the property which permits sand to be rammed, squeezed, or jolted around a pattern in such a way that the energy applied causes the sand to surround the pattern completely and be at a suitable, uniform hardness at the pattern surface without producing undesirable hardness conditions in other regions of the mold.* Hardness was used in measuring this property because it is a simple test to make and, for any one sand condition, it can be easily correlated with the other sand properties which are of equal importance in a mold.

5. Since sand must move to produce this required hardness condition, the motion of the sand is certainly not to be ignored.

6. A sand with good flowability, according to the above definition, would be one where the proper uniform hardness was obtained by the molding process with a minimum of applied energy, and where no other portion of the mold is so hard that the permeability properties have been impaired or that shaking-out becomes difficult.

#### *Sands Used*

7. During the investigation, most of the data was obtained on the sands listed in Table 1. As a check on some practical sands whose flowability properties were described as different by the foundrymen using them, tests also were made on a piston backing-sand and a piston facing-sand.

#### DESCRIPTION OF TESTS

8. Three basic tests were performed on all sand samples and from the data obtained, several methods of expressing flowability are discussed. A description of these tests follows. The sands for each test were prepared in a muller-type sand preparation unit.

**Table 1**  
**SANDS USED IN TESTS**

| Sand     | Clay,<br>Per Cent | Fineness<br>No. | Grain<br>Shape | Max. Perm.               | Max. Green                                 |
|----------|-------------------|-----------------|----------------|--------------------------|--|
|          |                   |                 |                | and<br>Per Cent Moisture | Comp. Strength<br>and<br>Per Cent Moisture |
| N.J. 125 | 18.4              | 118             | Sub-Angular    | 46 at 8.6%               | 16.8 at 5.5%                               |
| N.J. 60  | 16.0              | 61              | Sub-Angular    | 92 at 6%                 | 18.5 at 5.5%                               |
| N.J. 40  | 17.6              | 44              | Sub-Angular    | 200 at 5.5%              | 19.8 at 5%                                 |

#### *Hardness Gradient Method*

9. To determine flowability by this method, the mold and rammer shown in Fig. 1 were used. This mold is 1-in. thick and 12-in. wide.

10. With the rammer at the upper end of the mold in position for filling, the height of sand in the mold before ramming is  $12\frac{3}{4}$ -in. The mold is placed on its side on a table with the removable side plate off. The rammer is located at the top of the mold and the mold is filled with the sand to be tested by means of a hand riddle, care being taken to get good distribution. The ex-

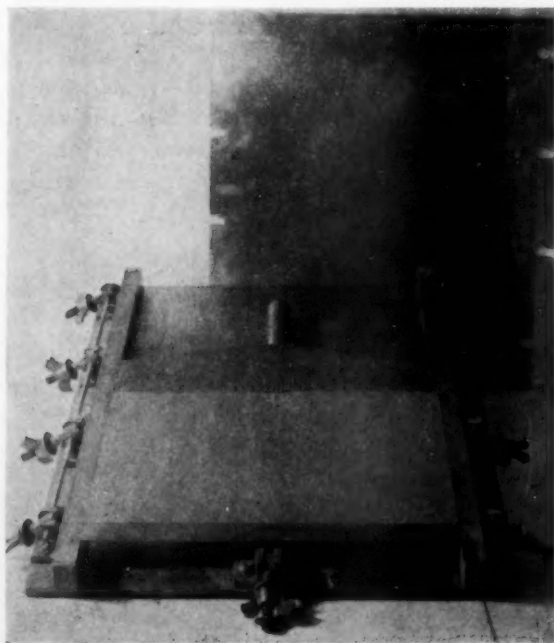


FIG. 1—HARDNESS GRADIENT TEST MOLD.

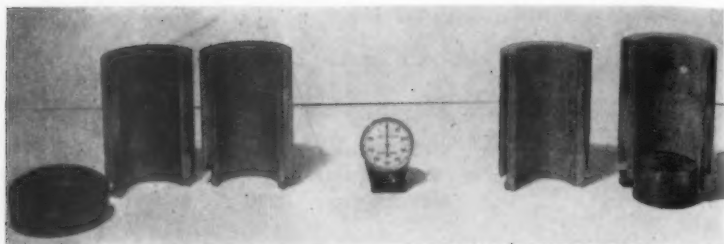


FIG. 2—SPLIT MOLD AND HARDNESS GAGE.

cess sand is struck off with a straight edge and the side plate clamped in position.

11. In the squeezing tests, the mold was put in a testing machine and force applied at the fastest rate possible. In the jolting test, the mold was filled without the rammer in position and the filled mold was jolted on the jolt platform used in the foundry laboratory. In the jolt-squeeze test, the jolting was done as described above, then the rammer was inserted and squeezing was done in the testing machine as before.

12. When the mold was properly prepared, it was placed on its side and the side plate removed. Hardness tests were made at frequent intervals from top to bottom of the mold at two sides and the center. Due to difficulty in getting the sand distributed uniformly in the corners of the mold in filling, it was decided to use only the readings at the vertical centerline of the mold in plotting the curves. In all cases, the center-line readings gave the most uniform results.

#### *Hardness Differential Method*

13. To express flowability as measured by this method, the mold shown in Fig. 2 and the rammer shown in Fig. 3 were used. The mold has a diameter of 2-in. and the amount of sand used to make the standard A.F.A. specimen 2-in. high was placed in it. The standard weight (14 lb.) was dropped once from a height of  $\frac{1}{4}$ -in. and hardness readings were taken at the top and bottom of the specimen. This procedure was repeated on new specimens rammed by varying amounts up to 16 blows in most cases.

#### *Sand Movement Method*

14. The method suggested by Dietert and Valtier<sup>1</sup> involves the measurement of the movement of the sand in the standard

<sup>1</sup> Dietert, H. W., and Valtier, F., "Flowability of Molding Sand," TRANSACTIONS, American Foundrymen's Association, vol. 42, pp. 199-210 (1934).

A.F.A. test specimen in the specimen tube after an initial ramming. The weight of sand needed for the standard specimen is placed in the tube and the 14-lb. rammer is dropped from a height of 2-in., four times. By means of a dial gage, the movement of the sand between the fourth and fifth blows of the rammer is recorded and is converted into a flowability percentage, as will be explained later.

15. In these tests, readings were taken of the movement of sand after each blow up to 6 to provide additional data on this method of measurement. The purpose of these tests was to get data on the only test for flowability proposed to date for comparison with the methods suggested in this paper. The apparatus used is shown in Fig. 3.

## RESULTS

### *Hardness Gradient Method*

16. By this method, it is proposed to consider that the ideal sand, to which a value of 100 per cent flowability would be assigned, is one which, when rammed to a certain top hardness or jolted to a certain bottom hardness, would develop the same hardness at all positions throughout the mold. If, therefore, a plot of

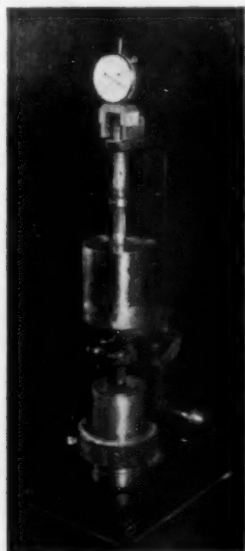


FIG. 3—RAMMER WITH SPLIT MOLD IN POSITION AND DIAL GAGE FOR MEASURING SAND FLOW.

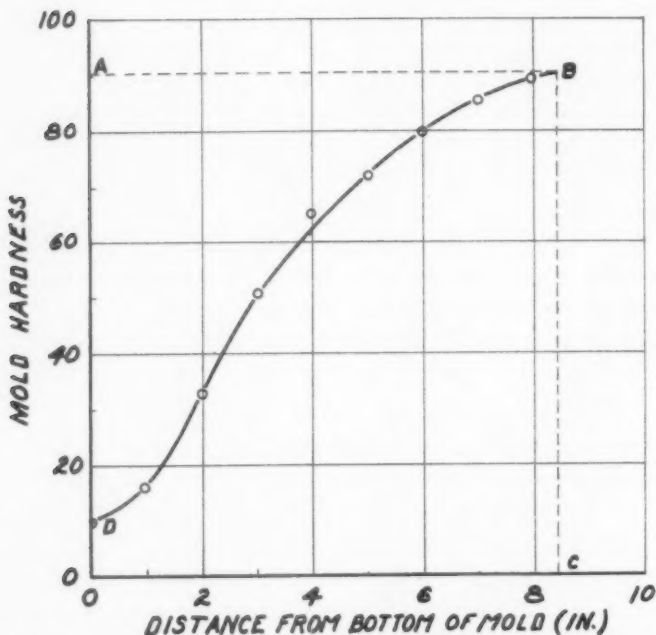


FIG. 4—HARDNESS GRADIENT CURVE OF N.J. 125 SAND AT 100 LB. PER SQ. IN. PRESSURE AND 6.8 PER CENT MOISTURE.

hardness vs. distance from the bottom of the mold was to be made, the line joining the points would be a straight one, such as line *AB*, Fig. 4.

17. If the results of the test on the N.J. 125 sand, as shown in Table 2, were to be plotted, the curve would be represented by the line *BD*, Fig. 4. This sand, therefore, would have poorer flowability characteristics than the ideal sand and one way of expressing this flowability numerically is to express the ratio of areas under the curves as a percentage. In this case

$$\text{Per Cent Flowability} = \frac{\text{Area DBCOD}}{\text{Area ABCOA}} \times 100 = 67.5 \text{ Per Cent}$$

18. Since flowability is not a property of the sand alone, it is necessary to point out that this value of per cent flowability is good only for comparing with other sands which have been prepared in the same manner, *i.e.*, squeezed at 1200-lb. (100-lb. per sq. in.) in a mold of the size and shape described in paragraphs

Table 2

## FLOWABILITY TEST DATA SHEET

| Mold Hardness Data    |     |   |     |    | Test No.                            | 125-6          |
|-----------------------|-----|---|-----|----|-------------------------------------|----------------|
| 15                    | —   | — | —   | —  | Date                                | August 2, 1939 |
|                       | —   | — | —   | —  | Sand Condition                      |                |
|                       | —   | — | —   | —  | Moisture                            | 6.8 %          |
|                       | —   | — | —   | —  | Permeability                        | 41             |
|                       | —   | — | —   | —  | Strength                            | 15.2           |
|                       | —   | — | —   | —  | Data Sheet F-125-N.J.               |                |
| 8%                    |     |   |     |    | Remarks                             |                |
| 8                     | 92  | — | 89  | 91 |                                     |                |
| 7                     | 89  | — | 86  | 89 |                                     |                |
| 6                     | 85  | — | 80  | 83 |                                     |                |
| 5                     | 75  | — | 72  | 71 |                                     |                |
| 4                     | 60  | — | 65  | 50 |                                     |                |
| 3                     | 37  | — | 51  | 27 |                                     |                |
| 2                     | 17  | — | 33  | 0  |                                     |                |
| 1                     | 0   | — | 17  | 0  |                                     |                |
| 0                     | 0   | — | 10  | 0  |                                     |                |
| Sand Rammer Indicator |     |   |     |    | Hardness ( $\frac{1}{4}$ -in. Drop) |                |
| Dial Rdg. Diff.       |     |   |     |    | Top Bot. Diff.                      |                |
| Before 1st Blow       | 833 |   |     |    | Before 1st Blow                     | 39 15 24       |
|                       |     |   | 392 |    |                                     |                |
| After 1st Blow        | 441 |   |     |    | After 1st Blow                      | 53 44 9        |
|                       |     |   | 115 |    |                                     |                |
| After 2nd Blow        | 326 |   |     |    | After 3rd Blow                      | 65 58 7        |
|                       |     |   | 61  |    |                                     |                |
| After 3rd Blow        | 265 |   |     |    | After 10th Blow                     | 80 78 2        |
|                       |     |   | 41  |    |                                     |                |
| After 4th Blow        | 224 |   |     |    | After 16th Blow                     | 81 80 1        |
|                       |     |   | 30  |    |                                     |                |
| After 5th Blow        | 194 |   |     |    |                                     |                |
|                       |     |   | 22  |    |                                     |                |
| After 6th Blow        | 172 |   |     |    |                                     |                |

9, 10 and 11. This is no failing of the test, however, since the ultimate choice of a standard flowability test will result in a comparative test, with comparisons being made with an adopted standard of reference.

19. To indicate the sensitivity of this test, Fig. 5 shows the hardness gradient curves for this same sand with different amounts of moisture and Fig. 6 shows the variation in flowability as measured from the plots in Fig. 5. The choice of 100-lb. per sq. in. in this case was made to insure a wide range of hardnesses up to

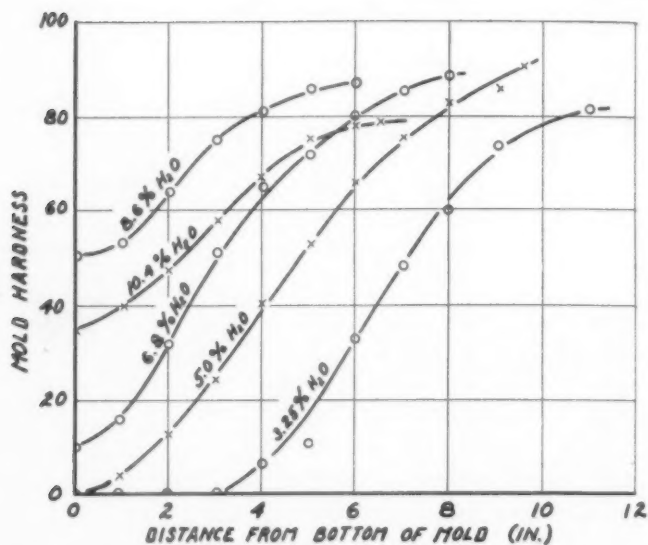


FIG. 5—HARDNESS GRADIENT CURVES OF N.J. 125 SAND AT 100 LB. PER SQ. IN. PRESSURE.

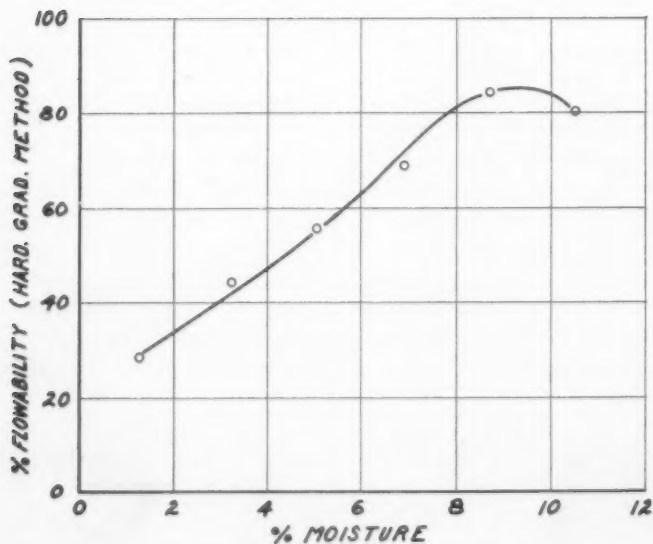


FIG. 6—FLOWABILITY VS. MOISTURE OF N.J. 125 SAND AT 100 LB. PER SQ. IN. PRESSURE.

those commonly used in a hard rammed mold. It is expected that any other choice of pressure would give different values of flowability but the values for different sands or sand conditions would bear the same relation to each other as they do at this pressure. Further experiments are necessary, however, to show if this is strictly correct.

### *Hardness Differential Method*

20. In Table 2, the data used to determine the merits of this method of measuring flowability are recorded. By the use of the standard rammer, it was found that one blow of the 14-lb. weight, dropped 2-in., was too severe to establish a differential from top to bottom of the specimen which would be greater than the permissible variation of readings which conform to the accuracy of the hardness meter. To get hardness differences, preferably of over 10 points, the  $\frac{1}{4}$ -in. drop had to be used.

21. If the hardness at the top and bottom are equal, the sand would be judged of ideal flowability and would be assigned the 100 per cent value. Likewise, it is possible to express flowability of any sand so tested as follows (N.J. 125 taking values after 1 blow for 6.9 per cent moisture)

$$\text{Per Cent Flowability} = \frac{\text{Hardness at Bottom } 44}{\text{Hardness at Top } 53} = \frac{44}{53} = 83 \text{ Per Cent}$$

22. It should again be noted that this value does not necessarily check the value obtained by the other method for the same sand and the same temper because the conditions causing flow are different. The conditions in this test correspond more perhaps to hand ramming procedure, while those for the hardness gradient method reported above, apply to squeeze-machine practice.

23. To point out the sensitivity of this test, Fig. 7 shows the flowability values obtained for several moisture contents, using the hardness differentials after one, three and ten blows. The data obtained after one blow seem to give the best sensitivity and it should be noted that the highest flowability is for the moisture content in the neighborhood of 8 per cent, which checks very well with the hardness gradient method.

### *Sand Movement Method*

24. The data taken according to the method suggested by Dietert and Valtier<sup>1</sup> are also shown in Table 2. The deformation

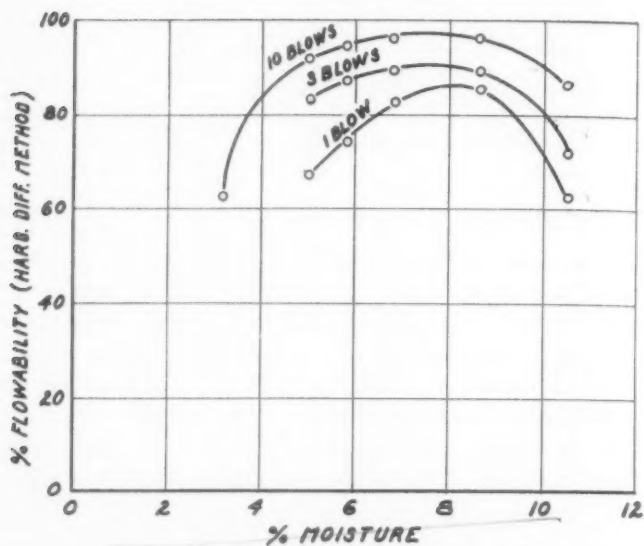


FIG. 7—FLOWABILITY VS. MOISTURE OF N.J. 125 SAND AS DETERMINED BY DROPPING 14 LB. WEIGHT  $\frac{1}{4}$ -IN. VARIOUS NUMBERS OF TIMES.

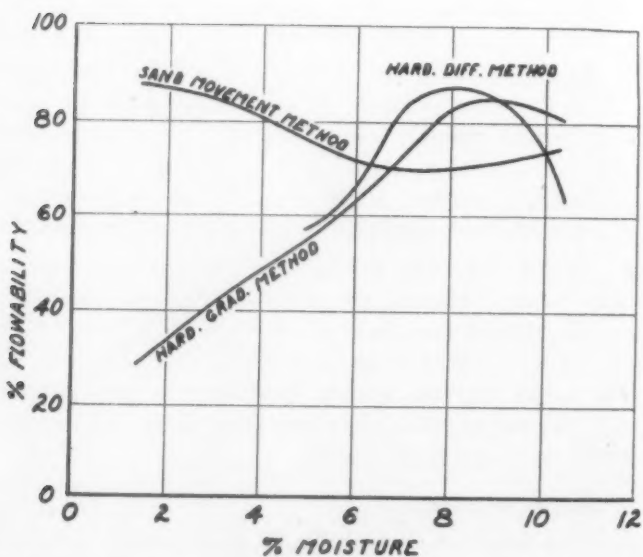


FIG. 8—COMPARISON OF METHODS FOR MEASURING FLOWABILITY OF N.J. 125 SAND.

between the fourth and fifth blows is given as 0.030-in. for the N.J. 125 sand at 6.8 per cent moisture.

Per Cent Flowability =  $1000 (0.100 - 0.030) = 70$  Per Cent

If the flowability of this sand is calculated at different moisture contents, the curve shown on Fig. 8 is obtained. This curve indicates the reverse relation of flowability vs. moisture for this sand when compared with the other tests.

25. Fig. 8 also shows a plot of flowability vs. moisture for the three methods discussed above.

#### DISCUSSION OF RESULTS

26. There are several indications that the hardness gradient method of expressing flowability is a sensitive method, provided the concept of hardness as an indicator is accepted. In Fig. 5, there are marked differences in hardness curves for slight differences in moisture content. As a further indication of its sensitivity, Fig. 9 shows the flowability for each of the three N. J. sands tested. Further study of these sands would undoubtedly show what effect the difference in fineness and strength of these sands had on these characteristic curves.

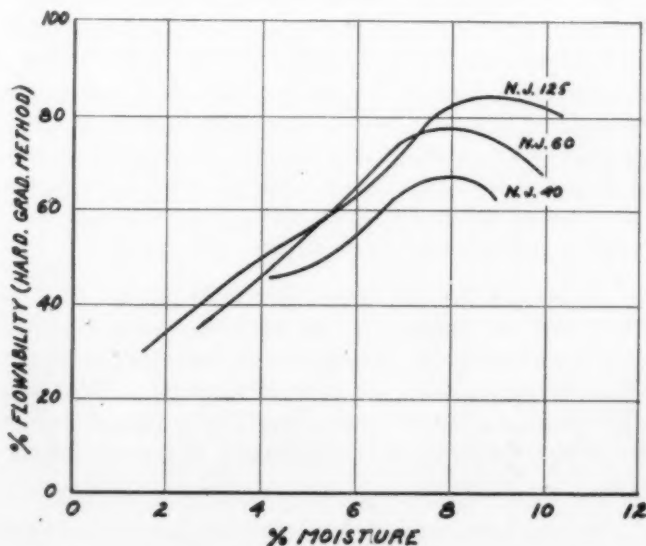


FIG. 9.—FLOWABILITY VS. MOISTURE OF THREE SANDS AT 100 LB. PER SQ. IN. PRESSURE.

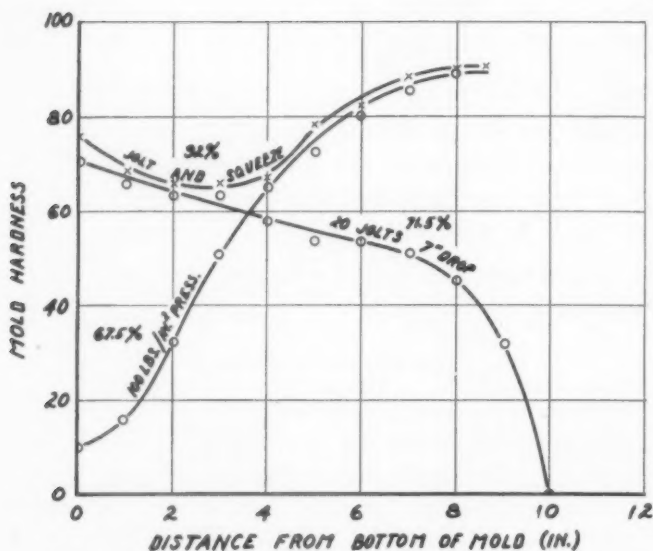


FIG. 10—HARDNESS GRADIENT CURVES FOR N.J. 125 SAND CONTAINING 6.8 PER CENT MOISTURE.

27. Fig. 10 is included also to show the merits of this test in showing differences in flowability with method of applying the ramming force. In the jolting process of mold preparation, one would expect the hardness gradient curve to be reversed from that obtained by squeezing. To obtain uniform mold hardness, it is quite generally conceded that the combined jolting and squeezing principle of molding is most effective. The results of these tests bear out this contention. Another very significant point which is shown by this series of curves is the need for specifying the method of mold preparation when discussing flowability and also the need for reference standards for each method used.

28. Regarding the hardness differential method, it does not seem likely that the ratio of bottom hardness to top hardness can be used for a deep mold because of the difficulty in eliminating errors due to non-uniform placement of the sand before ramming. When thinking of a shorter mold depth, it is logical to consider the use of the standard A.F.A. strength and permeability test specimen.

29. In the tests conducted to date by this method, there is some difficulty in obtaining uniformity of results and several tests

must be made to establish the flowability in each case. It is possible that further work on this method would eliminate some of the present difficulties. As compared to the hardness gradient method, this differential method is very desirable because it would require no special equipment and is rather simple.

30. In the method suggested by Dietert and Valtier<sup>1</sup>, the property being measured seems to be something akin to flowability as defined in this paper, but the method of expressing the results gives the reverse indication. In ramming sand with poor flowability, it is expected that the sand will not flow well and thus the hardness at the pattern will not increase as rapidly as with one of good flowability.

31. In the test which records the flow between the fourth and fifth blows of the rammer, it is possible that this inability to flow is an indication of poor flowability and, instead of being expressed as a high flowability, should be expressed as a direct ratio of flow in thousandths to 100 thousandths, the assumed maximum movement of the sand. Since this flow measurement is taken after the sand is rammed to a rather high hardness, the data might describe the action of the sand due to the weight of molten metal in the mold during pouring and not the flowability during ramming. If it happens that we eventually show the need for flowability data for both conditions, it would then be logical to have high flowability while ramming and low flowability while pouring.

32. As a clue to the possible explanation, it might be stated that the constant ramming force used in these tests by Dietert and Valtier would not necessarily give the same hardness condition. This can be seen from the curves in Fig. 5 where the pressure was 100-lb. per sq. in. for each moisture content. If the hardness criterion is still paramount in flowability, this may serve to explain the reverse relation.

33. In an attempt to check the effectiveness of the hardness gradient method of flowability measurement, some sands, which could be classified in a general way by the jolt machine operator as to flowability, were obtained and tested. The results of tests on these sands at temper are given in Table 3.

34. The significant features of these results are: (1) that the hardness gradient method of testing bore out the foundrymen's opinion of the sands for jolting, (2) that the sands varied in flow-

Table 3

## FLOWABILITY OF PISTON SANDS

| <i>Sand</i>            | <i>Hardness Gradient<br/>Squeeze,<br/>100 lb. per<br/>sq. in.</i> | <i>Jolt,<br/>20 Jolts—7 in.</i> | <i>Hardness,<br/>Differential<br/>Method,<br/>1st Blow</i> | <i>Sand<br/>Movement<br/>Method,<br/>4th-5th Blow</i> | <i>Foundryman's<br/>Rating of<br/>Flowability on<br/>Jolt Machines</i> |
|------------------------|---|---------------------------------|--|---|--|
| Piston Backing . . . . | 85  | 56                              | 80   | 64  | Poor   |
| Piston Facing . . . .  | 86  | 65                              | 79   | 60  | Fair   |

ability for jolting and not for squeezing and (3) that the Dietert test still gives the reverse relation for flowability when compared with the hardness gradient method.

## FUTURE RESEARCHES

35. From the results reported in this paper and the comments and criticisms received on the work done to date, it is expected that the investigation will be continued along the following lines:

1. Testing, by the proposed methods, of a sample of the standard sand in hope of getting reference standards to help determine pressures to use in testing by the gradient method, and ramming which will give the proper values of flowability by the differential method, if it is improved.

2. Critical study of the shape of the curves obtained in hope of establishing the laws of flow for this material, with constants for such items as clay content, moisture, fineness, etc.

3. Study of pressure—hardness curves for squeezing to see if the theoretical pressure to produce a hardness of 100 at some point in a standard mold, could be used as a number to rate sands as to flowability.

4. Further work in development of the hardness differential method of test in the hope that its simplicity can be retained and its accuracy and sensitivity increased.

5. Microscopic study of the flow action and an attempt to explain any laws of flow which may be developed by other methods.

## ACKNOWLEDGMENTS

36. The author wishes to acknowledge the assistance of F. R. Evans, H. E. Kiley, and E. L. Bartholomew, Jr. in the conduct of the tests, of I. J. Foote in the construction of equipment, and

R. F. Harrington and A. S. Wright, Hunt-Spiller Mfg. Corp., South Boston, Mass., for furnishing the sand used in the investigation. All tests were carried out in the sand control laboratory, Metal Processing Division, Mechanical Engineering Department, Massachusetts Institute of Technology.

### DISCUSSION

*Presiding:* W. G. REMCHERT, American Brake Shoe & Foundry Co., Mahwah, N. J.

H. W. DIETERT<sup>1</sup> (*Written Discussion*): The flowability data, as presented by Mr. Kyle, form a valuable addition to the knowledge on foundry sands. The author has indicated that the term "flowability" may have different conceptions by various workers of sand. Mr. Kyle seems to prefer to look upon flowability as that property of a sand to form a mold of uniform hardness, providing it is rammed correctly.

The writer wishes to take this opportunity to call your attention to the fact that one could have a high mold hardness and yet not secure a uniform and continuous mold surface. The mold may show a high mold hardness and also show void spaces between the sand grains. These void spaces are due to the inability of the sand grains to flow together, causing metal penetration. This is the type of flowability that the writer and Mr. Valtier defined in their paper\*. It is the writer's experience that

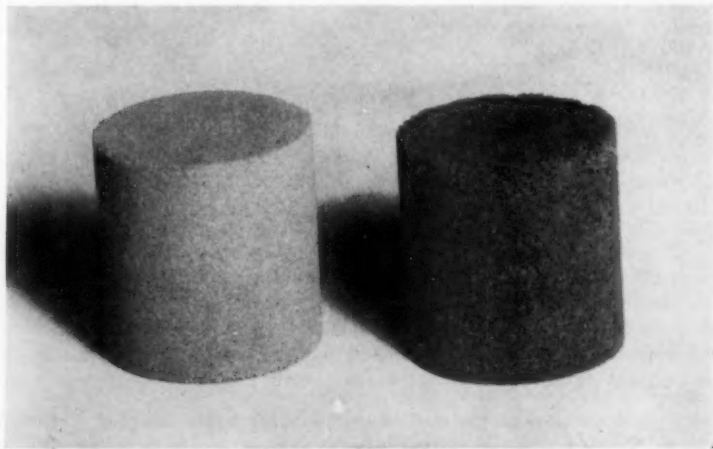


FIG. 11—SAND SAMPLES SHOWING COMPARATIVE FLOWABILITY OF TWO SANDS  
LEFT—SAND WITH FLOWABILITY OF 80. RIGHT—SAND WITH FLOWABILITY OF 64.

<sup>1</sup> Harry W. Dietert Co., Detroit, Mich.

\*Dietert, H. W., and Valtier, F., "Flowability of Molding Sand," TRANSACTIONS, American Foundrymen's Association, vol. 42, pp. 199-210 (1934).

this type of flowability is as essential as the flowability or ramability as defined by Mr. Kyle. A visual proof of the flowability that the writer refers to is shown in Fig. 11. Sand 1 has a flowability of 80 per cent while sand 2 has a flowability of 64. Note the void spaces of the mold produced by sand 2 while sand 1 makes a continuous mold surface without voids. The metal would penetrate into the voids of mold made from sand 2 and cause metal penetration defects. This illustrates the flowability property that the writer feels is of practical importance. For a further study of these two sands, see data tabulated in Table 4.

Table 4

STUDY OF FLOWABILITY OF MOLDING SANDS  
SAMPLE 1 — MOLD HARDNESS

| <i>Rammer<br/>Blows</i>          | <i>Appearance</i> | <i>Top</i> | <i>Bottom</i> | <i>Average</i> | <i>Difference</i> |
|----------------------------------|-------------------|------------|---------------|----------------|-------------------|
| 1                                | Close Grain       | 72         | 67            | 69.5           | 5                 |
| 2                                |                   | 80         | 72            | 76             | 8                 |
| 3                                |                   | 86         | 82            | 84             | 4                 |
| 4                                |                   | 86         | 86            | 86             | 0                 |
| 5                                |                   | 86         | 86            | 86             | 0                 |
| % Flowability, Dietert .....     |                   |            |               | 81             |                   |
| Green Compression Strength ..... |                   |            |               | 9.0#           |                   |

SAMPLE 2 — MOLD HARDNESS

| <i>Rammer<br/>Blows</i>          | <i>Appearance</i>       | <i>Top</i> | <i>Bottom</i> | <i>Average</i> | <i>Difference</i> |
|----------------------------------|-------------------------|------------|---------------|----------------|-------------------|
| 1                                | Bottom Half             | 63         | 62            | 62.5           | 1                 |
| 2                                | Rough and<br>Open Grain | 74         | 72            | 73             | 2                 |
| 3                                |                         | 75         | 74            | 74.5           | 1                 |
| 4                                |                         | 82         | 81            | 81.5           | 1                 |
| 5                                |                         | 84         | 84            | 84             | 0                 |
| % Flowability, Dietert .....     |                         |            |               | 64             |                   |
| Green Compression Strength ..... |                         |            |               | 4.7 #          |                   |

The data tabulated shows a mold hardness study of A.F.A. sand specimens made from sands 1 and 2. Sand 1 with a flowability of 81 per cent reaches a maximum hardness quickly while sand 2, with 64 per cent flowability, is very slow to reach a maximum hardness. With the percentage flowability test, as proposed by the writer, the indicator gives the best rating to a sand that rams together quickly.

Should one choose the mold hardness differential method, then from data in Table 4, sand 2, with the void spaces, would be given the best flowability. From the metal penetration on the casting, this assumption would prove incorrect.

The writer's foundry and laboratory experience has definitely shown that where one wishes to measure the ability of a sand to form a con-

tinuous uniform mold surface to eliminate false void spaces, causing metal penetration, the percentage flowability test is correct.

It is also the writer's opinion that the flowability factor studied by Mr. Kyle will be of practical importance. Further study is necessary to determine the field of application in the foundry.

H. F. SCOBIE<sup>2</sup> (*Written Discussion*): This study of flowability of molding sands is very interesting because it has led to many conclusions for which we have confirming data. Our conceptions of flowability seem to be much the same.

Some time ago during the course of an investigation, of which mold hardnesses were a routine part, it was noted that different proportions of water and binder produced different mold hardnesses. There was also an occasional case of lack of uniformity throughout the standard A.F.A. specimen. For example, there would be a variation in mold hardnesses on one end of a specimen, or around the middle circumference, which was outside the error expected in testing. Furthermore, hardnesses on the side of the specimen occasionally deviated from the usual gradient from the top to the bottom of the specimen. Since the specimens were all prepared by ramming the phenomenon was assigned some relation to "ramability." Ramability is the ability of molding sand to be rammed to uniform hardness, both vertically and laterally. The conception here is not as broad as when one quite properly speaks of flowability and includes all types of packing of molding sand.

In testing a sand for ramability we attempted to use the standard triple rammed specimen but variations due to lack of uniformity in filling the specimen tube were exaggerated (also true in the case of a single drop of the rammer) and the hardness differential was too small. Various functions of top hardness, face hardness, and bottom hardness were used to evaluate the data but only the following gave consistent results:

$$\frac{\text{Bottom Hardness}}{\text{Top Hardness}} \times 100 = \text{per cent ramability}$$

This value is calculated from mold hardness measurements made on the double rammed specimen of weight such that three rams would bring it within the required  $2 \pm \frac{1}{32}$ -in. length of the standard sand specimen.

The method just described gives results which are higher than those given by Mr. Dietert's sand movement method, and what is more important, the values are more consistent. The following trends have been noted from a study of student sand test reports for the winter quarter:

1. At the same moisture content, the flowability is lower with a clay of higher colloid content.
2. Flowability varies inversely as the green compressive strength unless the effect of high strength is nullified by the beneficial effect of certain clays.

<sup>2</sup>Instructor in Foundry Practice, University of Minnesota Institute of Technology, Minneapolis.

3. At the same moisture content a finer grain gives a lower flowability. This does not necessarily disagree with Fig. 9 since the particular sands in question were examined at only one strength.

The hardness gradient method is an excellent tool for the sand laboratory. Some of the work done here on a jolt-squeeze machine in a 14 x 16-in. flask confirms your data shown in Fig. 10. In connection with a study of hardness differences in molds, and the effect of uneven filling of the flask, hardness measurements were taken at one inch intervals over the face of carefully sectioned molds, cross-sections being taken at 4-in. intervals.

P. E. KYLE (*Author's Closure to Written Discussion*): The author appreciates the interest of all who contributed to the discussion and wishes to thank them for their comments and suggestions.

The fact that non-continuous mold surfaces of high hardness can be obtained as shown by Mr. Dietert is indicative that this property of flowability is a very complicated one. In the writer's experience with approximately 50 samples of sands comprising three New Jersey sands with varying moisture and degrees of ramming no voids such as shown in Fig. 11 sample 2 were noted. However, if any test for flowability is to be worth while it must necessarily distinguish between Mr. Dietert's two samples. It is hoped that this distinction can be made by means of some measurable quantity in the test and not by visual examination alone.

The hardness gradient method if applied to sample 2 would undoubtedly show a low flowability but this low value would be more of an indication of the slow rate of hardness increase than of the voids present.

Regarding Mr. Scobie's comments, we have not tested enough sands by these methods to discuss the effects of variables. Our experience with the small specimen has also indicated that the variation in hardness within one specimen is apt to mask the differences being measured. It is hoped that by the use of the larger mass of sand and the hardness gradient method certain of these inconsistencies will be eliminated.

In line with this work, Mr. Buchanan\* in the Foundry Trade Journal for March 14, 1940 suggests the use of the ratio of bottom hardness to top hardness on a specimen  $2\frac{1}{4} \times 1\frac{1}{2}$ -in. Any further work by our colleagues abroad should be of interest.

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\*Sand Testing with Special Reference to Deformation, p. 199-202.

## A Comparison of Refractories for Cupola Service

By J. A. BOWERS AND J. T. MACKENZIE\*, BIRMINGHAM, ALA.

### Abstract

*The authors studied the refractory costs for three cupolas, namely, the 21-in. and 54-in. diameter circular and the 102 x 72-in. link-shaped. Tests in the larger cupolas were conducted during a regular day's production holding all factors as constant as possible with the exception of the lining. Figures given include costs both with and without labor costs involved. The authors conclude, as a result of their studies, that each refractory investigated is economical under certain conditions.*

1. Naturally-formed stone has been used in the cupola as a refractory material for a number of years. To determine the relative merits of two kinds of local stone as compared to the ordinarily-used fire brick for refractory purposes at the American Cast Iron Pipe Company, a study was made in three production cupolas of different diameters, 21-in., 54-in. circular and 102 x 72-in. link-shaped. The tests in the larger stacks were conducted during a regular day's production, endeavoring to keep all other melting variables constant. The two natural stones tested consist mainly of silica, and are designated in this paper as stones *A* and *B*.

2. The actual chemical analyses of the materials tested are shown in Table 1.

### *Tests on 21-in. Diameter Cupola*

3. The first tests were made in the 21-in. diameter cupola in which the material to be tested was used as the entire lining in the melting zone. The method used for laying each refractory was that recommended by each manufacturer.

4. Stone *A* (shipping size,  $4\frac{1}{2} \times 6 \times 22$ -in. approx.), Fig. 1, was cut to length and placed tightly together using a regular daubing mud (60 per cent ground fire brick, 40 per cent fire clay, containing approximately 90 per cent  $\text{SiO}_2$ , by volume) as a mortar. Stone

\* Melting Superintendent and Chief Chemist and Metallurgist, respectively, American Cast Iron Pipe Co.

NOTE: This paper was presented at a Refractories Session of the 44th A.F.A. Convention, May 7, 1940, Chicago, Ill.

**Table 1**  
ANALYSES OF REFRACTORY MATERIALS USED IN TESTS\*

|                                       | Stone A    | Stone B | Fire Brick |
|---------------------------------------|------------|---------|------------|
| Alumina, per cent.....                | 0.51       | 2.78    | 29.08      |
| Iron Oxide, per cent.....             | 0.29       | 0.86    | 2.90       |
| Titanium Oxide, per cent..            | 0.40       | 0.20    | 1.80       |
| Calcium Oxide, per cent..             | 0.80       | 0.10    | } 1.14     |
| Magnesium Oxide, per cent             | 0.07       | 0.05    |            |
| Alkalies, per cent.....               | 0.16       | 0.28    |            |
| Loss on ignition, per cent            | 1.00       | 0.90    | ...        |
| Sulphuric Anhydride,<br>per cent..... | 0.19       | ...     | ...        |
| Silica, per cent.....                 | 95.58      | 94.87   | 62.68      |
| Fusion Point, °F.                     | Above 3200 | ...     | 3002       |

\* Analyses supplied by manufacturers.

*B* (shipped in slab form), Fig. 2, was placed with approximately  $\frac{1}{4}$ -in. between each slab using the same mortar. The firebrick was layed in the usual manner, *ie.*, as close together as possible using a soupy mortar made of the same ingredients as previously mentioned.

5. After preparing the cupola in the usual manner, melting was continued until a visible hot spot appeared on the shell of the cupola. The raw material making up the charge consisted of 100 per cent steel scrap with enough ferro-alloys to give the desired spout analysis. Table 2 gives the pertinent data concerning these heats.

6. To get a more comparable basis of comparison, stone *A*

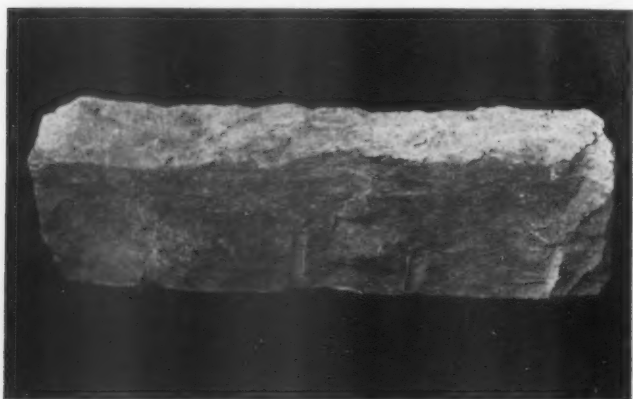


FIG. 1—STONE A, USED IN THESE TESTS, IS SHIPPED IN SIZES  $4\frac{1}{2} \times 6 \times 22$ -IN. APPROXIMATELY.



FIG. 2—STONE B IS SHIPPED IN SLAB FORM.

must be credited with certain savings that would be realized from less frequent relining of the cupola, since there would be less bed coke, flux and other expenditures necessary in the preparation of the cupola to obtain the same tonnage than with the other two refractories. This is due to the fact that the cupola would have to be relined and fully prepared three times with fire brick and stone *B* and only twice when using stone *A* to melt the same amount of iron. The total savings per ton, including labor, materials, gas, power, etc., amounts to \$0.31 per ton and subtracting this from the cost for stone *A* in the Table 2, the more comparable cost is as follows:

|   | <i>Fire Brick</i> | <i>Stone<br/>A</i> | <i>Stone<br/>B</i> |
|---|-------------------|--------------------|--------------------|
| Cost per ton for refractories<br>including labor..... | \$ .63            | \$ .89             | \$ .59             |

7. These costs are comparable only and are not indicative of the actual refractory cost in the regular operation of this stack for a usual heat of 8-hr. The above costs were based on the fact that all the refractory material in the melting zone was consumed during these test heats and this is practically true, because the small amount of lining remaining was so thin that, in chipping away the slag after each heat, it collapsed.

8. To study the relative merits of the two lower cost materials, additional heats were made lasting the usual 8-hr. and patching the melting zone after each heat to its original diameter. In a period of 2 weeks, the cupola liner had gained enough experience

with stone *B* so that he could complete the patching job for the same cost as when using fire brick. The results of 6 days' refractory consumption and cost are given in Tables 3 and 4.

Table 2

## DATA ON HEATS RUN IN 21-IN. DIAMETER CUPOLA

|   | <i>Fire Brick</i> | <i>Stone<br/>A</i> | <i>Stone<br/>B</i> |
|---|-------------------|--------------------|--------------------|
| Iron to coke ratio.....                               | 9.2 to 1          | 9.3 to 1           | 9 to 1             |
| Amount of Flux, per cent<br>iron charge.....          | 5-Dolo.           | 4.5-Dolo.          | 5-Dolo.            |
| Average wind pressure, oz.....                        | 2.7               | 2.5                | 2.7                |
| Spout temperatures, °F.....                           | 2650              | 2690               | 2650               |
| Total Iron melted, lb.....                            | 14,400            | 21,800             | 14,200             |
| Length of heat, hr.....                               | 10.6              | 13.0               | 10.1               |
| Man hours required for lining.                        | 2                 | 5                  | 4                  |
| Melting rate, tons per hr.....                        | 1.6               | 1.4                | 1.6                |
| Cost per ton for refractories..                       | \$ .47            | \$ .91             | \$ .25             |
| Cost per ton for refractories<br>including labor..... | \$ .63            | \$1.20             | \$ .59             |

Table 3

## FIRE BRICK REFRACTORY COSTS ON 21-IN. CUPOLA

| <i>Tons<br/>Melted</i> | <i>Cost of<br/>Fire Brick<br/>For Patching</i> | <i>Cost per<br/>Ton with<br/>Fire Brick</i> |
|------------------------|--|---|
| 5.2                    | \$ 0.68  | \$ 0.130                                    |
| 3.7                    | 0.78   | 0.211                                       |
| 4.1                    | 0.74   | 0.180                                       |
| 4.1                    | 0.83   | 0.202                                       |
| 4.3                    | 0.84   | 0.195                                       |
| 5.0                    | 0.95   | 0.190                                       |
| Avg. 4.4               | 0.803  | 0.185                                       |

Table 4

## STONE B REFRACTORY COSTS ON 21-IN. CUPOLA

| <i>Tons<br/>Melted</i> | <i>Cost of<br/>Stone B<br/>For Patching</i> | <i>Cost per ton<br/>With<br/>Stone B</i> |
|------------------------|---|--|
| 4.3                    | \$ 0.67                                     | \$ 0.155                                 |
| 4.2                    | 0.60  | 0.150                                    |
| 4.4                    | 0.71  | 0.162                                    |
| 4.4                    | 0.61  | 0.139                                    |
| 4.3                    | 0.58  | 0.135                                    |
| 4.3                    | 0.70  | 0.163                                    |
| Avg. 4.4               | 0.645                                       | 0.161                                    |

*Tests on 54-in. Diameter Cupola*

9. The next series of tests were made in a 54-in. diameter cupola operated about  $4\frac{1}{2}$ -hr. a day melting approximately 50-tons. The tests were conducted on stone *A* and fire brick only since stone *B* in the previous tests had been about the same as fire brick from a refractory standpoint. The charge in this cupola consisted of 3 per cent steel scrap, 25 per cent miscellaneous scrap, and the remainder pig iron. All other raw materials were the same for all heats and the operation was held as near the same for each heat as possible.

10. The method adopted to test the life and comparable cost of refractories was to line the stack to its proper diameter, *i.e.*, 54-in., and then allow this original lining to burn back in the melting zone to a point that was considered dangerous before patching. The practice followed for the heats when no patching was done, was to chip any adhering slag from the stack, clean the tuyeres and prepare the bottom in the usual manner.

11. The point, when patching was considered necessary, was determined by actual measurement of the increase in diameter in the melting zone and was approximately the same before each patching, since the refractories burned away in a comparatively uniform manner around the stack. Regular 9-in. straights and splits were tried but the results were not as satisfactory as the use of the proper size cupola block, when patching to this depth.

12. Tables 5 and 6 show that when stone *A* was used in the melting zone, an average of 5 heats were made before it was necessary to repatch. When cupola blocks were used, the life of the patching averaged only 1½ heats.

13. Table 5 gives the data concerning heats using cupola blocks and Table 6 using stone *A*.

**Table 5**

REFRACTORY COSTS IN 54-IN. CUPOLA USING CUPOLA BLOCKS

| <i>No. of days<br/>On each lining</i> | <i>Wind<br/>Pressure<br/>oz.</i> | <i>Total Tons<br/>Melted</i> | <i>Total Cost<br/>Refractories<br/>Per Ton</i> |
|---------------------------------------|----------------------------------|------------------------------|--|
| 2                                     | 15 to 16                         | 79.8                         | \$ 0.203                                       |
| 2                                     | 15 to 16                         | 85.1                         | 0.132  |
| 1                                     | 15 to 16                         | 41.6                         | 0.155  |
| Avg. 1½                               | 15 to 16                         | 68.8                         | 0.163  |

Table 6

## REFRACTORY COSTS IN 54-IN. CUPOLA USING STONE A

| <i>No. of days<br/>On each lining</i> | <i>Wind<br/>Pressure<br/>oz.</i> | <i>Total Tons<br/>Melted</i> | <i>Total Cost<br/>Refractories<br/>Per Ton</i> |
|---------------------------------------|----------------------------------|------------------------------|--|
| 5                                     | 15 to 16                         | 307.6                        | \$ 0.044                                       |
| 4                                     | 15 to 16                         | 154.9                        | 0.073  |
| 5                                     | 15 to 16                         | 298.7                        | 0.045  |
| 7                                     | 15 to 16                         | 380.8                        | 0.041  |
| 6                                     | 15 to 16                         | 343.8                        | 0.048  |
| 4                                     | 15 to 16                         | 200.0                        | 0.047  |
| 6                                     | 15 to 16                         | 245.6                        | 0.066  |
| Avg. 5                                | 15 to 16                         | 275.9                        | 0.052  |

14. Experience has proved in this type of operation, that no extra labor is necessary for patching this stack when using stone. To check the cost of the former method employed in these stacks, *i.e.*, patching after each heat with 9-in. straights and splits, comparative data was kept for several typical heats and are shown in Table 7.

Table 7

REFRACTORY COST USING FIRE BRICK WHEN PATCHING  
AFTER EACH HEAT

| <i>Average<br/>Wind<br/>Pressure,<br/>oz.</i> | <i>Total Tons<br/>Melted</i> | <i>Total Cost of<br/>Refractories<br/>Per Ton</i> |
|---|------------------------------|---|
| 15 to 16                                      | 38.8                         | \$ 0.051  |
| 15 to 16                                      | 37.5                         | 0.050   |
| 15 to 16                                      | 38.8                         | 0.092   |
| 15 to 16                                      | 41.3                         | 0.091   |
| 15 to 16                                      | 37.5                         | 0.090   |
| 15 to 16                                      | 42.5                         | 0.073   |
| 15 to 16                                      | 45.0                         | 0.043   |
| 15 to 16                                      | 40.0                         | 0.059   |
| Avg. 15 to 16                                 | 40.2                         | 0.067   |

*Tests on Link-Shaped Cupola*

15. The last series of tests were conducted in the link-shaped cupolas, 72 x 102-in. The iron charge in these stacks consisted of 16 per cent steel, 20 per cent return scrap and the remainder pig iron. The iron to coke ratio, excluding the bed, averaged 10 to 1, and all other raw materials were the same for each heat. The data collected and shown in Tables 8 and 9, were for heats of 8 hr. duration with the normal tonnage of from 20 to 30 tons per hour being

melted. Tables 10 and 11 give data for heats of 16 hr., in which the cupola was melting at its normal rate during the first 8 hr., but at only half its normal rate the last 8 hr.

16. The method adopted for these tests was to line the melting zone one-half the way around the stack with the natural refractory and the other with regular fire brick. The costs shown in Tables 8, 9, 10 and 11 were obtained by dividing the cost of relining each half of the cupola by the total tons melted.

17. The above costs are indicative only, since the cost per ton for each material is that necessary for patching only half of the melting zone. This cost does not include removing the debris from the cupola drop but only the cost of refractory material and the

**Table 8**

COST OF REFRACTORIES IN LINK-SHAPED CUPOLAS  
(Eight hour operation — Average of 11 heats)

|  | Stone A   | Fire Brick |
|--|-----------|------------|
| Average Tons Melted.....                         | 242.9     | 242.9      |
| Average Refractory Cost.....                     | \$ 0.0291 | \$ 0.0313  |
| Average Refractory Cost,<br>Including Labor..... | 0.0400    | 0.0433     |

**Table 9**

COST OF REFRACTORIES IN LINK-SHAPED CUPOLAS  
(Eight hour operation — Average of four heats)

|  | Stone B   | Fire Brick |
|--|-----------|------------|
| Average Tons Melted.....                         | 226.2     | 226.2      |
| Average Refractory Cost.....                     | \$ 0.0202 | \$ 0.0347  |
| Average Refractory Cost,<br>Including Labor..... | 0.0366    | 0.0472     |

**Table 10**

REFRACTORY COSTS IN LINK-SHAPED CUPOLAS  
(Sixteen hour operation — Average of two heats)

|   | Stone A   | Fire Brick |
|---|-----------|------------|
| Average tons melted.....                        | 397.8     | 397.8      |
| Average Refractory cost.....                    | \$ 0.0305 | \$ 0.0264  |
| Average Refractory cost<br>Including labor..... | 0.0379    | 0.0359     |

**Table 11**

REFRACTORY COSTS IN LINK-SHAPED CUPOLAS  
(Sixteen hour operation — Average of five heats)

|   | Stone B   | Fire Brick |
|---|-----------|------------|
| Average tons melted.....                        | 386.6     | 386.6      |
| Average Refractory cost.....                    | \$ 0.0267 | \$ 0.0169  |
| Average Refractory cost<br>Including labor..... | 0.0264    | 0.0233     |

labor necessary to actually place each material in the melting zone properly. It should further be pointed out that the labor required for patching with the natural stones might be reduced to some extent by the experience gained through its continued use.

#### DISCUSSION OF RESULTS

18. The results indicated from the tests shown in Table 2, are that stone *A* is a super-refractory when compared to the other two materials tested. However, due to its extremely high cost, it is not economical for all types of operation.

19. The data obtained in the 54-in. diameter cupola supports the first results. These data, along with that in Table 7, show further that for the type of operation used in this stack, stone *A* is more economical, in spite of its high initial cost, than either of the methods tried with the particular fire brick used in these experiments.

20. The test results in the large cupolas indicate that there is very little to choose between the three materials for the 8-hr. operation. When these stacks are operated 16 hr. fire brick proved the more economical.

#### CONCLUSIONS

21. From the previously mentioned data, the following conclusions may be drawn:

(1) We may safely conclude from these results that all three refractories may economically fill certain needs in the foundry. The place for each will have to be determined by each foundry through experiments.

(2) The results obtained, show clearly that stone *A* is a super-refractory and, in spite of its high initial cost, may prove more economical in some operations.

(3) Stone *B* is about equal to the fire brick used in these tests from a refractory standpoint and can, because of its cheapness, be used economically in some types of operations in spite of the high labor cost necessary to lay it.

(4) The fire brick used in these tests was not excelled in certain operations, particularly where cupola lining labor costs are relatively high.

(5) One of the most important things to be learned from this type of investigation is the importance of periodic cost studies of refractory consumption in any foundry.

## DISCUSSION

*Presiding:* A. H. DIERKER, Ohio State University, Columbus, O.

C. K. DONOH<sup>1</sup> (*Written Discussion read by Mr. Bowers*): The paper by Messrs. Bowers and MacKenzie presents valuable service records on three refractory materials for cupola linings. An important phase of refractory selection, however, is the preliminary testing of an untried material in order to determine first if the material is sufficiently serviceable to warrant a trial in production service. Brief description and examples are herewith given of the method of preliminary testing of untried refractories as used at the American Cast Iron Pipe Company.

A small test cupola is lined from bottom door to above the melting zone with a lining material of known value in one-half of the shell and with the material to be tested in the other half. After careful measurement, the cupola is operated for a period sufficient to give significant attack of the lining. The cupola used has a 30-in. diameter shell and 4½-in. of lining reduces the operating diameter to 21-in. There are two tuyeres on opposite sides of the cupola and the line between the two refractories is made at the tuyeres so that anything happening to one tuyere will not destroy the value of the test.

After sufficient operation of the cupola, which is used for experimental or alloy iron heats, the adhering slag and coke are carefully chipped away from the lining and measurements of the depth of lining attack are made and recorded. Both the original and final measurements are made by use of a straight edge laid between reference points on the shell at the bottom of the cupola and at the charging sill. Depths of "burning in" are measured and recorded for 10 horizontal planes 3-in. apart, which gives a rather complete three-dimensional picture of the attack on the lining.

In the accompanying Fig. 3, each half of the cupola is considered as laid out flat and depth of "burning in" at the various planes is indicated by the shaded curves. The material tested was a southern natural stone which was suggested for cupola use. However, since this test showed definitely that the material was quite inferior for cupola service to the standard fire brick, this material was never tried in production service. Fig. 4 shows results of the preliminary test on the stone A discussed by Bowers and MacKenzie. In this case, it is obvious that the tested stone has significantly greater resistance in the cupola than the standard fire brick. From this test, stone A was considered worthy of trial in the larger cupolas in regular production.

This preliminary test method has proved valuable in this foundry for cheaply and effectively rating likely but untried refractories, which in some cases have eventually proved economical.

<sup>1</sup> Metallurgist, American Cast Iron Pipe Co., Birmingham, Ala.

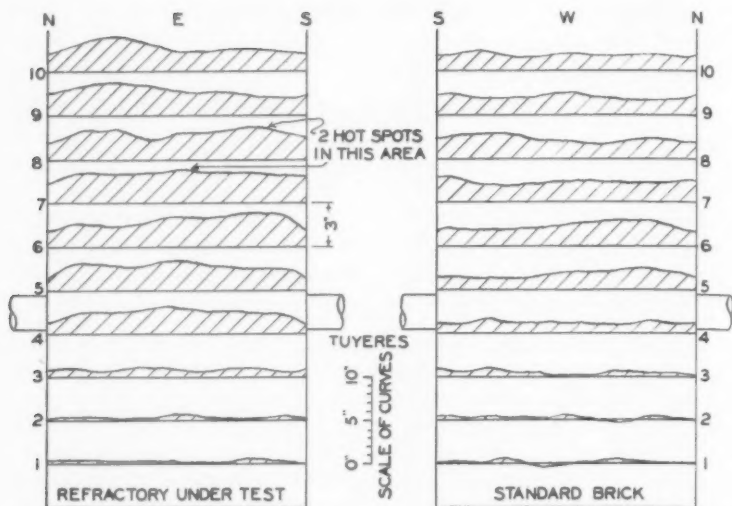


FIG. 8.—COMPARATIVE TEST OF CUPOLA LINING MATERIALS. SHADED AREA SHOWS LOSS OF REFRACTORY. SECTIONS 3-IN. APART.

W. D. McMILLAN<sup>2</sup>: I noticed stone *B* contained quite a little alumina and slightly more alkali, 0.3 per cent as against 0.16 per cent; the iron oxide also was a little higher. Is not the significant factor there that the difference in the efficiency of the two stones was due to the higher alumina content, or did you make any effort to try to determine that?

MR. BOWERS: We do not think it is due to the chemical composition. We think it is due to the physical nature of the stone. Both of them are natural stones, but stone *B* comes in definite layers, whereas stone *A* is uniform in structure throughout and very difficult to break along a given line. One of the reasons why stone *A* is so expensive is because it is very difficult to mine.

MR. McMILLAN: Stone *B* has a definite cleavage plane in one direction. Could that be laid in so the cleavage plane was horizontal and better results obtained than if the plane was vertical?

MR. BOWERS: Somewhat better, but in these tests it was all laid vertically; because the slabs would fit better, they could be laid so much faster. An important item in using stone *B* was the high cost of labor necessary to lay it.

CHAIRMAN DIERKER: Do you feel, then, Mr. Bowers, that part of the loss on stone *B* was due to spalling and not so much due to the lack of refractoriness?

<sup>2</sup> Metallurgist, International Harvester Co., Chicago, Ill.

**MR. BOWERS:** Not only to spalling but also to abrasion. As the stock would come down, the stone would tend to flake off due to abrasion to a certain extent, as well as spalling. The difference was not so great but there was definitely a difference between the two methods of laying. But, since the stone comes in slab form, one is almost forced to lay it the way we did in these tests to keep the labor costs within reason.

**W. A. O'BRIEN<sup>3</sup>:** I have used stone in conjunction with firebrick for the past 11 years and I would like to know just how high above the tuyeres the stone was used and as to whether the stone was run clear to the charging door or just to the top of the melting zone and then on up with clay block or iron block?

**MR. BOWERS:** The stone was just used in the melting zone in all of the tests given in this paper. The height of the melting zone had been clearly established because, as stated in the paper, all three of these stacks are used in production daily, so we knew the height of the melting zone and we put the stone only in it.

**C. S. REED<sup>4</sup>:** Mr. Bowers, on the question of this test, not long ago I got the records on a rather exhaustive test that was run on six different types of refractories. The comment was made on the results of that test to this effect, that the depth to which the various refractories were burned back in the melting zone was relatively unimportant; that the greatest factor of importance was the vertical width of the attack. I was told

<sup>3</sup> Plant Supt., Electric Auto-Lite Co., Fostoria, O.

<sup>4</sup> Chicago Retort and Firebrick Co., Chicago, Ill.

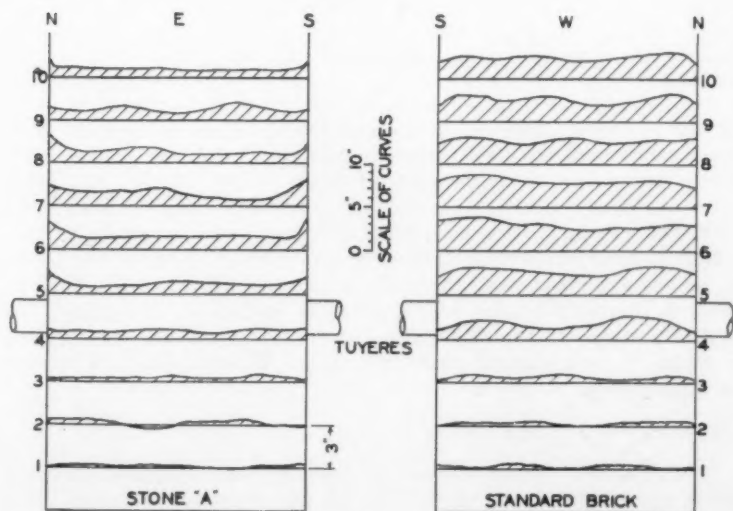


FIG. 4—COMPARATIVE TEST OF STONE A FOR CUPOLA LINING. SHADED AREA SHOWS LOSS OF REFRACTORY. SECTIONS 3-IN. APART.

the reason for this was that there was a very definite spot in the melting zone that was hotter than any other, and that spot was relatively stationary in the operation of the cupola. Being above the fusion point of the refractories, it would be expected that all of them would be eroded back to a certain depth but that the less refractory material would be attacked to a greater vertical width of band than the more refractory material.

Have you had any experience along that line or have you any comments you could make on that?

MR. BOWERS: We have always found that the height of attack was proportional to the wind pressure, the velocity of the air traveling up the stack, and also that there would be a difference if using hot blast as compared to cold blast. For instance, we have several hot blast cupolas in our shop and, in the hot blast stack, for a given pressure, we have a narrow, deep melting zone, whereas in the cold blast for the same pressure, it is shallow and high. If the hot blast stack is operated at 15 oz. pressure, we get a narrow attack but rather deep, and at higher pressure the attack extends higher. The depth will depend on the quality of the refractory and to some extent the length of heat.

MR. REED: Assuming that the test is run on the same cupola on consecutive days, using different types of refractory material, do you think then the width of that band of attack is more indicative than the depth of erosion, or otherwise?

MR. BOWERS: Actually, that is not the way we ran these tests to arrive at these costs, because we filled the entire space eroded away in every instance. I would hardly know what to say in answer to that. We do think that the depth of attack and the height of attack above the tuyeres, is proportional to the velocity of the air going up the stack rather than a measure of the goodness of the refractory.

MR. O'BRIEN: In this discussion, would it not be better to state that the region of activity of the combustible gases is confined to a shorter range with hot blast than with cold blast? I firmly believe, from my own experience, that regardless of what we use, whether it is coke, pig iron or other material, we blame it onto whatever we can. Regardless of whether we are using a good refractory, good coke or good pig iron, we must balance our tuyere ratio with the inside diameter of our stack, and, as you explained here about the short range with the hot blast as compared to the increased range with the cold blast, it confines the chemical reaction of the dissociation of the hydrogen and the oxygen. We confine it to a smaller space with a hot blast cupola than with a cold blast cupola.

MR. BOWERS: That is right.

C. E. BALES<sup>5</sup>: We have been hearing for quite a number of years various stories about the superiority of one type of refractory over

<sup>5</sup> Vice President, Ironton Fire Brick Co., Ironton, O.

another. This series of tests shows fairly conclusively that one material is just about as good as another and it depends upon the location of the plant and the character of their operations as to just what type of refractory material will prove the most economical.

I was particularly interested in the 16-hr. tests, because there, the author shows that refractory brick is more economical on those runs than firestone. I think that is very vital.

Another point is in regard to high labor costs. I do not believe that his costs in the South are nearly as high as they are in the highly industrialized areas in Michigan, the Northern part of Ohio and Wisconsin. It would be interesting if we could have some results along similar lines obtained in plants in those territories.

## Report of Committee on Radiography — 1940

*To the Steel Division, American Foundrymen's Association:*

Your Radiographic Committee during the past year (May, 1939 to May, 1940) has followed radiographic developments carefully and because of its associations and connections in the A.S.T.M. has been active in the deliberations of that body.

We believe that considerable advancement has taken place in the field of industrial radiography during the year. A number of steel foundries have used radiography for the first time this year and a number of them are using radiography in a routine manner. Several foundries are advertising in the industrial press and by circulars that they are prepared to furnish castings radiographically examined.

Committee E-7 of the A.S.T.M. accomplished two things of considerable interest to foundrymen during the past year. The *Recommended Practice for Radiographic Testing of Metal Castings* (E 15-29) was revised and brought up to date by the addition of material on X-ray and gamma ray radiography. Certain passages objectionable to foundrymen were deleted and the new proposed Tentative Methods (E15-39T) were accepted by the A.S.T.M. and appear in the 1939 Book of A.S.T.M. Standards, Part I.

Committee E-7 also adopted as a radiographic standard the Gamma-ray radiographic standards of the U. S. Navy Bureau of Engineering for steel castings for steam pressure service. The A.S.T.M. has not published these standards as yet. There appears to be some delay due to the inability of deciding on the method of reproduction of the radiographs.

This is the first standard the Committee has accepted, but it is

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NOTE: This report was presented at Steel Session of the 44th A.F.A. Convention, May 10, 1940, Chicago, Ill., by C. W. Briggs.

believed that other standards will be presented to the Committee shortly.

Committee E-7 sponsored 4 technical papers at the Annual Meeting of the A.S.T.M.

A paper by T. A. Triplett and W. L. Howland<sup>1\*</sup> shows results obtained with an X-ray tube whose projected focal area is only 0.1 mm in diameter. They studied wrought and cast aluminum alloys. The focal spot is the smallest that has been used for routine industrial radiography in the country. They found interesting correlations between micrographic structure revealed in radiographic tests and tensile impact values.

An excellent picture of the practical application of radiographic tests to the manufacture of cast crankshafts was presented in a paper by D. M. McCutcheon.<sup>2</sup>

A paper presented by Dr. H. H. Lester<sup>3</sup> was based upon cooperative work of several industrial laboratories. The work was sponsored by and reported to the Joint A.P.I.-A.S.M.E. Radiographic Committee. The paper brought out some very interesting and long-needed information on sensitivity in testing with X-rays and the value of sensitivity gauges.

G. E. Doan and M. B. Vordahl<sup>4</sup> presented a paper wherein they made a study using very small radium capsules and showed that good definition may be obtained with radium source as close as 3-in. to a  $\frac{3}{4}$ -in. plate. The significance of the results lies in the fact that they point the way to a practical method of testing welded pipe lines.

Sub-Committee VI on Safety, of Committee E-7 sponsored a very important paper entitled "*Industrial X-ray Protection*"<sup>5</sup> by L. S. Taylor of the National Bureau of Standards. Points discussed were: Tolerance dose, lead and other protective barriers, protection against direct and scattered radiation and the location of X-ray tubes.

A correlated abstract of important papers in the radiographic field was also presented to Committee E-7 and the literature for 1938 appears in correlated form<sup>6</sup> so that all interested in this subject can review recent worthwhile information.

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\* Superior figures refer to papers listed in bibliography.

During the year articles on radiography other than those sponsored by the A.S.T.M. appeared in the Industrial Press.

An article by R. C. Wood<sup>7</sup> showed that extreme care must be taken in the handling of X-ray films or else the film is apt to show some defect caused by carelessness. The author discusses certain points that should be kept in mind while developing X-ray films. Some of these points are understanding of the process of developing, dust-laden atmospheres, contamination of films by fingers, scratching, etc.

F. W. Rowe<sup>8</sup> published a very interesting review of radiographic inspection and the manner in which radiography is being used in Great Britain.

An article by A. E. Cartwright<sup>9</sup> presented information on the X-ray inspection of aluminum alloy aircraft castings as being carried on in Canada.

In an article entitled "*Radiography*,"<sup>10</sup> Kent Van Horn presented information on radiographic developments during the year 1939. He discussed the new type of X-ray equipment that is now available and the interesting developments in accessories.

In an article devoted mostly to review, C. W. Briggs<sup>11</sup> discussed radiography as applied to the casting industries. Subjects discussed: radiographic specifications, interpretation, radiography as an aid to designers and an aid in manufacturing.

R. G. Tobey<sup>12</sup> published an article on industrial radiography in which he takes up the improvements in radiography such as latest advances in equipment, technique of continuous and planar inspection, type of protection, intensifying screens, etc.

A review of industrial X-ray radiographic equipment and procedure was also presented by H. Isenburger.<sup>13</sup>

During the past year the National Bureau of Standards put out a booklet on Radium Protection. This booklet is mostly for the use of medical workers but many things within its pages apply to the industrial radiographer.

The Navy recently sent out an interesting letter bulletin in which they called attention to the fact that radiographic examination was being extended for future construction on all steel castings

for main propulsion turbine castings, main steam chests, main steam line fittings and main steam valves. They also pointed out that it is desirable that radiographic examination be given to principal castings such as stem castings, stern posts, struts, rudder castings, stern tubes, turret roller patch castings and other castings subjected to shock.

The above is called to the attention of the members of the Steel Division merely to point out the trend of conditions and that radiography has become another inspection method that the steel foundries must be ready to perform.

Your Committee plans for the coming year to include the re-issuing of the 1937 Questionnaire with certain changes.\*

*Respectfully submitted*

COMMITTEE ON RADIOGRAPHY

C. W. Briggs, *Chairman*

R. H. Frank  
W. C. Hamilton

G. F. Landgraf  
P. E. McKinney

E. W. Page  
L. C. Wilson

\* *Report of Committee on Radiography*, TRANSACTIONS, American Foundrymen's Association, vol. 46, p. 280-296 (1938).

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12. Tobey, R. G., "*Industrial Radiography.*" IRON AGE, pp. 27-30, Feb. 29, 1940; pp. 64-67, March 7, 1940.
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14. "*Radium Protection.*" NATIONAL BUREAU OF STANDARDS HANDBOOK H-23.

# The Relationship Between the Physical and Mineralogical Characteristics of Bonding Clay†

BY RALPH E. GRIM\* AND RICHARDS A. ROWLAND\*, URBANA, ILL.

## Abstract

*Data are presented to show that the kind and amount of clay mineral in a clay are the most important factors determining its bonding strength. The relation between these factors is discussed. The problem of the break up of the clay mineral in clays, such as might be brought about by mulling, is analyzed in relation to bonding strength.*

## INTRODUCTION

1. The object of the investigation reported herein was to study the fundamental factors controlling the variations in the bonding properties of clays. It is a well recognized fact that all clays do not possess the same bonding characteristics, but the factors that determine the variations have not been well understood. This report is the fourth<sup>1, 5, 6</sup> of a series reporting the results of the Illinois State Geological Survey's project for the investigation of the fundamental properties of bonding clays and molding sands.

2. In recent years, it has been shown that most clays and shales are made up of extremely small particles, frequently less than 0.001 mm. (1/25000 in.), of a limited number of minerals known as the clay minerals. Stated another way, clays and shales are essentially aggregates of extremely minute particles of one or more of the clay minerals. The most common clay minerals are noted in Table 1.

3. In addition to clay minerals, clays and shales also may contain varying amounts of quartz, organic material, limonite

† Published with the permission of the Chief, Illinois State Geological Survey.

\* Petrographer and Assistant Petrographer, respectively, Illinois State Geological Survey.

NOTE: This paper was presented at the Foundry Sand Research Session during the 44th annual A.F.A. convention held in Chicago, May 8, 1940.

Table 1  
CHEMICAL COMPOSITION AND OCCURRENCE OF COMMON CLAY MINERALS

| <i>Name</i>     | <i>Chemical Composition*</i>  | <i>Occurrence</i>                         |
|-----------------|---|---|
| Montmorillonite | $(\text{OH})_4 \text{Al}_4 \text{Si}_8 \text{O}_{20} \cdot x\text{H}_2\text{O}$   | Bentonites, gumboils, etc.                |
| Illite          | $(\text{OH})_4 \text{K}_y (\text{Al}_4 \cdot \text{Fe}_4 \cdot \text{Mg}_6) (\text{Si}_{18-y} \cdot \text{Al}_y) \text{O}_{20}$ | Shales, gumboil, underclays, etc.         |
| Kaolinite       | $(\text{OH})_8 \text{Al}_4 \text{Si}_4 \text{O}_{10}$   | Underclays, fire clays, china clays, etc. |

\* Certain substitutions are possible in these general formulae. For details see Grim, R. E., "Relation of the Composition to the Properties of Clay," Illinois Geological Survey, Circular 45, 1939.

(hydrated ferric iron oxide), etc. Of the non-clay mineral constituents, quartz, in the form of grains, is by far the most abundant and most common. Clays differ from each other fundamentally in the clay minerals that compose them, in the amount of admixed quartz or other non-clay mineral constituents, and in their texture (size of particles, etc.).<sup>1\*</sup> It is the purpose of this report to present the results of a study of the influence of these fundamental differences between clays on their bonding characteristics.

#### PROCEDURE

4. In the past eight years, the complete mineral composition of a large number of clays and shales has been determined by x-ray and microscopic methods in the laboratory of the Illinois State Geological Survey. From these clays and shales, a group was selected for the present investigation that exhibited wide variations in composition and texture. The clays selected are not all commercial bond clays. The clays used, were chosen so that the results would provide a broad picture of the effect of different characteristics of clays on their bonding properties.

5. The green compression strength of each sample, at several different moisture contents, was determined using 8 per cent clay and 92 per cent sand (except for the bentonite sample when 4 per cent clay and 96 per cent sand were used). These determinations were carried out according to A. F. A. standard procedure except that the sand\* used had a fineness number of 56 instead of 50.

6. For each sample, the amount of material coarser than the A. F. A. clay grade<sup>2</sup> and the size grade distribution within the A. F. A. clay grade were determined by the pipette method<sup>3</sup>. Any method for the determination of the size grade distribution of a clay or shale requires that the clay or shale be first broken down in water into a suspension. The results obtained are always dependent to some degree on the amount the clay or shale has been disaggregated in water prior to the analysis. In other words, widely different size grade distribution determinations may be obtained from a single clay by the use of different amounts and kinds of disaggregation.

<sup>1\*</sup> Superior numbers refer to bibliography at end of paper.

\* The sand used comes from the Ottawa, Ill., district and is regularly sold as "bond" sand.

7. In the present research, great care was used to carry out the disaggregation of all samples in exactly the same manner so that the results would be comparable. The disaggregation procedure followed was mild, *i. e.*, no attempt was made to break the clays or shales down to anything like their ultimate particle size. The mild procedure was followed because in the actual use of clays or shales for rebonding, they are in general not immediately broken down to their ultimate particle size. It was felt that the following procedure disaggregated the clay to about the same degree as in the actual use of the clay for rebonding and, therefore, that the results would be particularly significant in an understanding of the variations of the bonding properties of clays or shales.

8. The clay or shale was first ground to pass a 70-mesh screen and then soaked in water for 7 days. During the soaking period, the clay and water were agitated about once every 12 hours. Ammonium hydroxide ( $\text{NH}_4\text{OH}$ ) was used as the dispersing agent.

#### ANALYTICAL DATA

9. The determinations of maximum green compression strength, moisture content at maximum strength, quantity of clay minerals, clay mineral composition, and quantity of material in the A. F. A. clay grade are given in Table 2. The per cent of clay mineral in the entire sample was determined by means of microscopic examination. In some clays and shales, the clay minerals occur in individual particles and aggregate masses that are larger than the upper size limit of the A.F.A. clay grade, *i. e.*, 0.020 mm.

10. The quantity of A. F. A. clay given in Table 2 is that portion of the sample shown by the pipette analyses to be less than 0.020 mm. in diameter. The disaggregation procedure preliminary to the pipette analyses was a very mild one which did not reduce all the clay mineral aggregates or large individual particles in all samples to a size smaller than 0.020 mm. As a consequence, the table shows the total amount of clay mineral to be more than the A. F. A. clay for some samples.

11. The determinations of the size grade distribution of each sample within the A. F. A. clay grade are given in Fig. 1. The distribution curves in Fig. 1 were constructed by the graphic differentiation method<sup>4</sup> from cumulative curves plotted from the results of the pipette analyses. The distribution curves show the

Table 2  
PROPERTIES AND CLAY MINERAL CONSTITUENTS OF CLAY  
FOUND IN VARIOUS LOCATIONS

| Sample No. | Location   | Per Cent Clay in Strength Mixture | Maximum Green Compression Strength, lb. per sq. in. | Per Cent Water at Maximum Strength | Per Cent A. F. A. Clay Grade†† | Per Cent Clay Mineral in Total Sample | Clay Mineral Constituents                  |
|------------|--|-----------------------------------|---|------------------------------------|--------------------------------|---------------------------------------|--|
| 1          | Bentonite, Wyoming.....                            | 4                                 | 9.6   | 1.00                               | 95.0                           | 95                                    | Montmorillonite—100                        |
| 2          | Eocene clay, Pulaski Co., Ill....                  | 8                                 | 18.0  | 3.12                               | 66.1                           | 70                                    | Montmorillonite—90*                        |
| 3          | Pennsylvanian underclay<br>Grundy Co., Ill.....    | 8                                 | 13.6  | 1.92                               | 81.9                           | 90                                    | Illite—80†, Kaolinite—20                   |
| 4          | Pennsylvanian underclay<br>Madison Co., Ill.....   | 8                                 | 12.0  | 1.70                               | 56.0                           | 90                                    | Kaolinite—85, Illite—10, Montmorillonite—5 |
| 5          | Pennsylvanian underclay<br>Madison Co., Ill.....   | 8                                 | 9.9   | 1.43                               | 65.6                           | 75                                    | Kaolinite—85, Illite—10, Montmorillonite—5 |
| 6          | Pennsylvanian shale<br>Green Co., Ill.....         | 8                                 | 8.6   | 1.68                               | 49.0                           | 90                                    | Illite—90, Kaolinite—5, Montmorillonite—5  |
| 7          | Pennsylvanian underclay<br>Grundy Co., Ill.....    | 8                                 | 8.2   | 1.41                               | 64.8                           | 75                                    | Kaolinite—65, Illite—35                    |
| 8          | Pennsylvanian underclay, Ohio..                    | 8                                 | 8.2   | 1.5-2.2                            | 88.7                           | 75                                    | Kaolinite—75, Illite—25                    |
| 9          | Residue, Ordovician dolomite<br>Kane Co., Ill..... | 8                                 | 8.2   | 1.68                               | 75.5                           | 70                                    | Illite—100                                 |
| 10         | Pennsylvanian shale<br>St. Clair Co., Ill.....     | 8                                 | 7.2   | 1.67                               | 72.1                           | 90                                    | Illite—80, Kaolinite—20                    |
| 11         | Pennsylvanian shale<br>Tazewell Co., Ill.....      | 8                                 | 6.3   | 1.55                               | 91.8                           | 80                                    | Illite—90, Kaolinite—10                    |
| 12         | Pennsylvanian shale<br>Sangamon Co., Ill.....      | 8                                 | 6.1   | 1.60                               | 65.5                           | 70                                    | Illite—90, Kaolinite—10                    |
| 13         | Pleistocene clay<br>Livingston Co., Ill.....       | 8                                 | 3.4   | 1.60                               | 69.4                           | 50                                    | Illite—100                                 |
| 14         | Pleistocene clay<br>Livingston Co., Ill.....       | 8                                 | 2.4   | 1.20                               | 43.0                           | 30                                    | Illite—100                                 |

\* This sample contains a small amount of another clay mineral that cannot be identified positively. It appears to be either chlorite or kaolinite.

† The illite in this sample is unusual because of its low content of potassium oxide and certain of its physical properties. See Journal American Ceramic Society 25, pp. 157-164, 1939.

†† This is the amount of material finer than 0.020 mm. obtained by the pipette analytical procedure used in the present study.

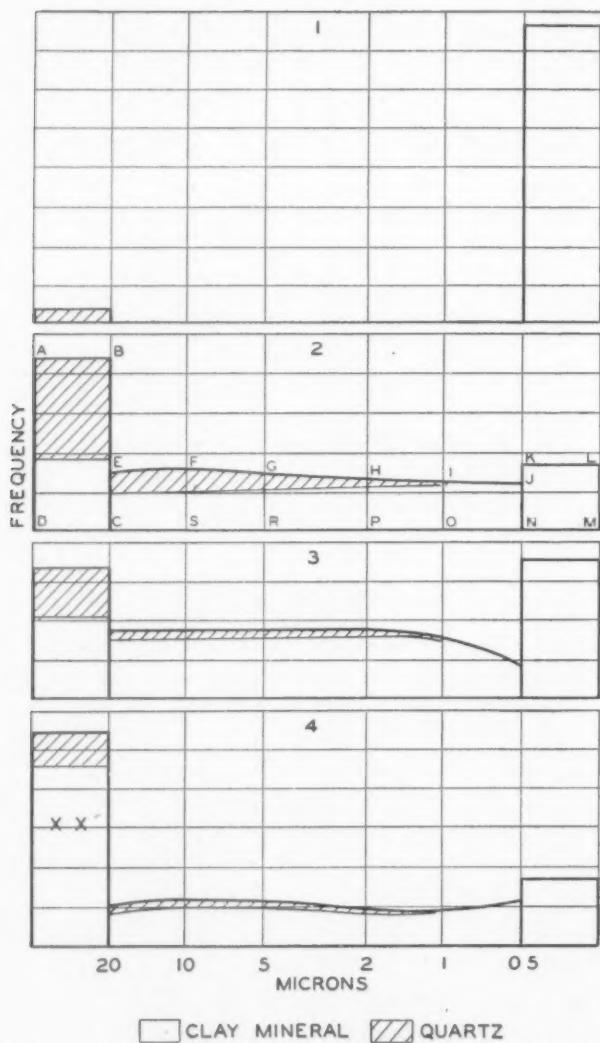


FIG. 1—Size Grade Distribution Curves. 1 MICRON IS EQUAL TO 0.001 MM. FOR THE SIGNIFICANCE OF THE "XX" SEE PAGE 219.

amount of material between any given size limits by the proportion of the area under the curve between the given size limits to the area beneath the entire curve.

12. For example in curve No. 2, the area (*EFSC*) beneath the curve and between vertical lines constructed at the 0.020 mm. and

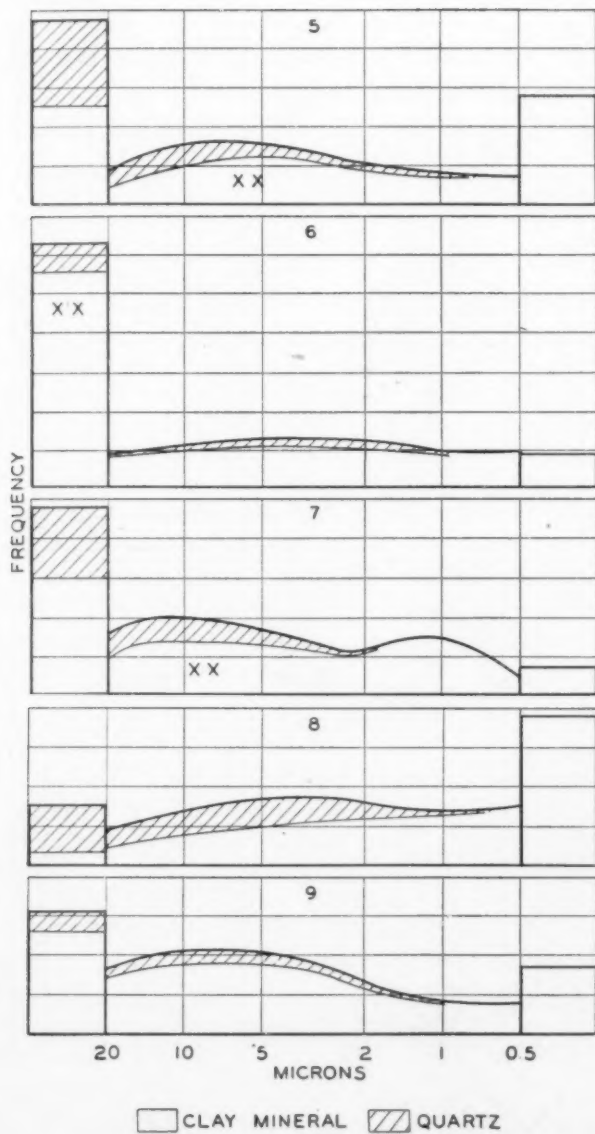


FIG. 1 CONTINUED.

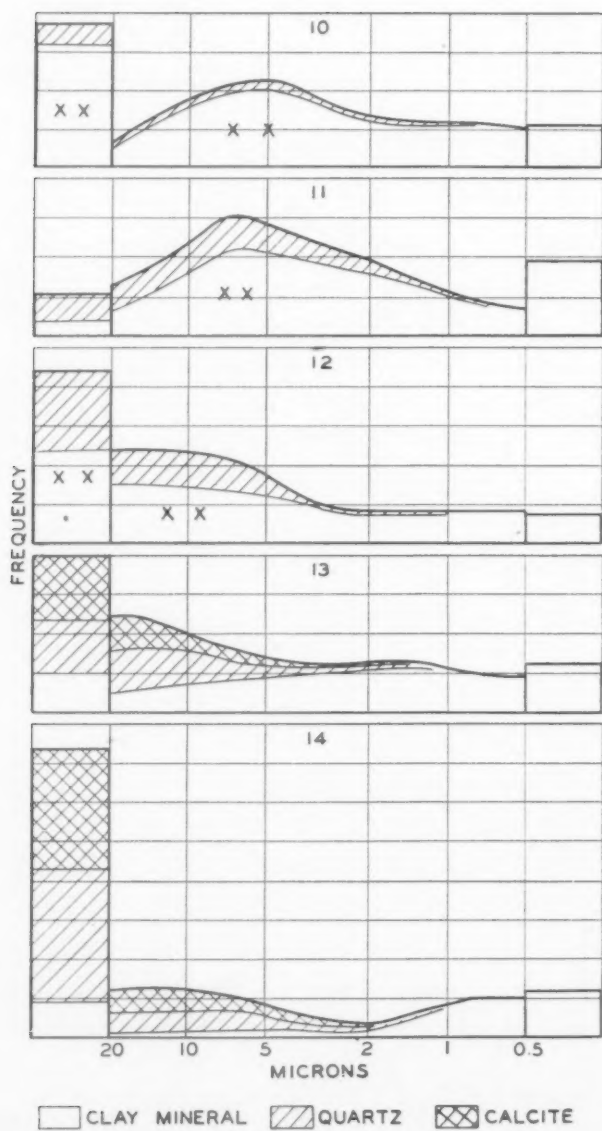


FIG. 1 CONTINUED.

0.010 mm. points is 11.2 per cent of the area beneath curve (*EJNC*), plus the rectangular areas (*ABCD* and *KLMN*) and therefore 11.2 per cent of the sample is in the 0.020 mm. to 0.010 mm. grade size. The area of the rectangle (*KLMN*), on the right, in proportion to the area under the curve (*EJNC*) plus the area of the rectangles (*ABCD* and *KLMN*) represents that portion of the sample smaller than 0.0005 mm. in size (12.7 per cent for sample No. 2). The rectangle (*ABCD*), on the left for sample No. 2, has an area equal to 33.9 per cent of the area under the curve (*EJNC*) plus the areas of rectangles (*ABCD* and *KLMN*) and, therefore, indicates that 33.9 per cent of the sample is composed of particles larger than 0.020 mm. in size.

13. In the curves in Fig. 1, the cross-hatched areas represent the amount of calcite, the parallel ruled areas represent the amount of quartz, and the remaining area represents the amount of clay mineral. The amount of these minerals in the samples as a whole or in the individual size grades can be obtained from the curves by comparing areas. The clay mineral material occurring in the coarser size grades, for example  $\pm 0.005$  mm., may be either aggregates of smaller particles or individual particles of the size indicated. Where the size grade is composed primarily of individual particles of clay minerals rather than aggregates, the designation "XX" is used.

#### SIGNIFICANCE OF DISTRIBUTION CURVES

14. The size grade distribution curves in Fig. 1 show that there may be a tremendous variation in the size distribution of particles for different clays. Thus, one clay material (No. 1) has most of its particles smaller than 0.0005 mm. whereas another (No. 12) has very few particles finer than this size. Some samples (Nos. 1 and 11) have very few particles coarser than the A.F.A. clay grade, i.e., 0.020 mm., whereas other samples (Nos. 4 and 6) have many particles coarser than this size. One clay (No. 2) has a very even distribution of particles between 0.020 mm. and 0.0005 mm., whereas another one (No. 11) has an uneven distribution of particles between these sizes.

15. The distribution curves in Fig. 1 are arranged in the order of decreasing green compression strength of the clay materials they represent, No. 1 having the greatest and No. 14 the least strength. A critical analysis of the size distribution data of these

samples in relation to their bonding strength, brings out the fact that there is no precise correlation between any single size distribution characteristic, or combination of them, and the bonding strength of the clay materials. For example, there is no correlation between the amount of A.F.A. clay grade as determined in this study and the green compression strength; also there is no correlation between the amount of material finer than 0.0005 mm., and the green compression strength. This means that some other factors are dominant in controlling the bonding strength of clay materials. It will be shown presently that the amount and character of the clay mineral content are the dominant factors.

16. One might conclude, on the basis of theoretical considerations and microscopic study of clay-bonded sands, that a clay composed chiefly of extremely minute particles (less than 0.001 mm.), or of larger particles that broke down immediately when used to such minute particles, would have the highest bonding power, other factors being equal. This conclusion would seem to follow, because smaller particles would give a greater total surface area in the clay for bonding purposes, and microscopic study<sup>7</sup> shows that a very fine-grained clay evenly coats the sand grains while another clay of larger particle size coats the quartz grains irregularly with many large clay lumps between grains that can have little influence on the strength of the sand-clay mixture.

17. In the clays studied, the sample composed of the finest particles has the greatest strength (No. 1). However, sample No. 2 with about the same clay mineral composition is composed of much larger particles and yet has about the same strength as sample No. 1. Data from other samples support the conclusion that a raw clay need not necessarily be composed of extremely minute particles ( $\sim 0.001$  mm.) to be a good commercial bonding clay. In fact a clay composed of somewhat coarser particles of clay mineral may have certain advantages over one composed only of extremely minute clay particles. If the coarser clay contains clay mineral particles that break down into minute particles with fair rapidity when the clay is worked, the clay will probably have better durability because breaking down of the clay mineral particles will continue to provide new bonding surfaces as the clay is being used.

18. It should be emphasized that only the clay mineral particles in a clay possess bonding strength<sup>5</sup>, and that only the clay

mineral particles can easily and readily be broken into smaller sizes when the clay is worked, *e.g.*, in mulling. The clay mineral particles are flake-shaped and their breakdown tends to take place by cleavage of the flakes. Although clay mineral particles tend to occur in clays generally in particles less than 0.002 mm., individuals and aggregates are frequently 0.020 mm. or more in diameter in many clays and shales.

19. In general the clays studied that have a relatively even distribution of particles, between 0.020 mm. and 0.0005 mm., also have high green compression strength. The explanation seems to be that such clays do not contain large amounts of non-clay mineral material in particles smaller than 0.020 mm. and also that they are composed of clay mineral particles and aggregates that break down with reasonable rapidity into extremely minute particles. A critical consideration of the data indicates that a clay composed of large clay mineral particles that does not break down into very fine particles is not a satisfactory bonding clay. On the other hand a satisfactory bonding clay is not necessarily one composed only of very fine particles, or of larger particles that break down immediately when the clay is first used. A clay composed of particles that break down with intermediate ease is apt to be a most satisfactory bonding clay (other factors of clay mineral composition, *etc.*, being equal).

20. Those clays studied that show an irregular distribution between 0.020 mm. and 0.005 mm. are also those that contain a large amount of non-clay mineral material, or an abundance of large clay mineral particles that do not break down easily. In either case the sample has low bonding value because it contains a large proportion of material with little or no bonding power.

#### SIGNIFICANCE OF CLAY MINERAL COMPOSITION

21. Data obtained in the present work substantiate the conclusion of an earlier paper<sup>5</sup> that the clay mineral composition is the most important factor in determining the bonding strength of a clay. The data also verify the conclusion that montmorillonite is the clay mineral providing the highest strength (samples 1 and 2), and that the presence of a small amount of montmorillonite in a clay will raise the bonding strength out of all proportion to the actual amount of the montmorillonite. This is illustrated by comparing the green compression strength of samples 4 and 5,

which contain small amounts of montmorillonite in addition to kaolinite and illite, with samples 7 to 12 which contain only kaolinite and illite.

22. The present data show that kaolinite and most illite materials have much lower bonding strength than clays composed of montmorillonite, and that kaolinite clays have higher strength than most illite materials. The characteristics of illite vary within wide limits and the data indicates that occasionally an illite clay may have very high bonding power. For example, sample No. 3 composed largely of illite has very high strength. Chemical data, obtained in another study, show that there is a range in the potassium oxide ( $K_2O$ ) content of the illite clay minerals, and that in general clay materials composed of illite with relatively high  $K_2O$  content have low green compression strength.

23. It is significant that one of the attributes of montmorillonite and the certain illite (*e.g.*, sample No. 3) is that they either occur in extremely minute particles or in larger particles that break down easily into very small particles. Kaolinite, and particularly illite with a high  $K_2O$  content, tend to occur in particles of larger size that break down with difficulty into particles of very small size. One, but probably not the only reason for the difference in bonding power of the different clay minerals, is the variation in the ease with which they break down into very fine particle size.

24. A comparison of samples 2 and 8 emphasizes the importance of the clay mineral composition in determining bonding strength. Sample No. 2 has much less material finer than 0.0005 mm. and much more material coarser than 0.020 mm. than has sample No. 8, yet sample 2 is the stronger clay because it is composed of montmorillonite. In both samples the actual amount of clay mineral is about the same.

#### INFLUENCE OF THE AMOUNT OF CLAY MINERAL

25. The data in Table 2 illustrate that there is a relation between the amount of clay mineral in clay materials of the same clay mineral composition and their bonding strength. Thus samples 13 and 14 with low clay mineral content have very low bond strength. The data suggest further that the non-clay mineral content does not reduce the bond strength of a clay or shale very much

unless there is more than about 30 per cent of it present. In other words non-clay mineral matter tends to have little effect on bond strength unless it makes up more than 30 per cent of the total clay material.

#### SUMMARY

26. The green compression strength of fourteen clays of widely different compositions was determined, at 8 per cent clay and 92 per cent sand (except bentonite—4 per cent clay and 96 per cent sand).

27. Pipette analyses of these clays were made using mild disaggregation procedure. These analyses show approximately the effective particle sizes of the clays as they exist when the clay is used in the foundry.

28. An analysis of the size distribution of the clays in conjunction with their green compression strength shows that those clays which break down with intermediate ease are apt to be most satisfactory (other factors of clay mineral composition, etc., being equal).

29. A comparison of the kind of clay mineral with bonding strength indicates that clays composed of montmorillonite have the greatest green compression strength. Clays composed of kaolinite and illite have lower bonding strength. An example of an unusual illite clay is given that has high green compression strength. A small amount of montmorillonite present in a mixture with either kaolinite or illite yields a bonding strength out of all proportion to the amount of montmorillonite present.

30. The presence, in amounts greater than about 30 per cent, of such materials as quartz, calcite and/or large clay mineral flakes which do not break down easily cause low bonding strength.

31. There is a relation between the amount of clay mineral and the bonding strength in clays of the same clay mineral content.

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